TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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STORMWATER RUNOFF MANAGEMENT AND SURVEILLANCE DURING CONSTRUCTION – CASE VUORES

Master of Science Thesis

Examiner: Professor Jukka Rintala
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ABSTRACT

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Stormwater runoff should be treated during construction, and especially from pollutants and sediments that are induced by excavations. Urbanization affects the catchment hydrology increasing runoff and pollutant flushes. During construction, the changes occur in phases, and cold climate and seasonal variations complicate them further. The stormwater runoff threatens receiving waterbodies and possibly the human health. Sediments transported from construction sites end up in receiving waterbodies and in the drainage system, possibly clogging the system causing financial losses. Pollutants are transported in stormwater runoff and discovering the sources and transportation systems of pollutants prevents detriments. Other important information is pollutant response to rain events and pollutant association to particulate matter and the effects of changing seasons.

Stormwater runoff management begins in the planning stage. The sediment transportation needs to be controlled and surface soil should be covered as widely as possible. It is important to maintain the stormwater runoff management systems and inspect the construction sites regarding it. The stormwater runoff in construction sites is treated with best management practices, which are based on filtration and sedimentation. Monitoring stormwater runoff is challenging due to variability of pollutant concentrations and flows. The inspections are important in order for the stormwater runoff management to function at construction sites. Runoff management begins is important in decision making and includes many stakeholders.

The purpose of this thesis was to study construction time stormwater runoff in Vuores, which is located in Tampere. To create an inspection protocol, inspection needs were looked for during field observations, and possible stormwater pollutants were charted from samples. On-site observations were analyzed as such and in a larger context. The pollutant concentrations were levelled up with the development of the area in Vuores, especially during the rain event and as associated with particulate matter. Sulfate concentrations were also high at some parts of Vuores. Observations at construction sites revealed that space was scarce and thus joint management systems should be favored. Sediments are already managed in some extent in Vuores, but still sediments and erosion protection need to be paid attention, especially during rain events. Winter, snow and its melting are also significant. Furthermore, the maintenance of finished systems, such as ditches, needs to be attended to. The stormwater runoff management would benefit from an inspection protocol created on a basis of this thesis.

TIIVISTELMÄ

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Hulevesiä tulisi suojella rakentamisen aikana, erityisesti maan muokkaamisesta ja kaivamisesta aiheutuvilta haitta-aineilta ja sedimenteiltä. Kaupungistuminen vaikuttaa valuma-alueen hydrologiaan lisäten valumaa ja haitta-ainehuuhtoumaa. Rakentamisen aikana muutokset näkyvät vaiheittain rakentamisen edetessä. Viileä ilmasto ja vuodenaikojen vaihtelut mutkistavat kaupungistumisen aiheuttamaa muutosta entisestään. Likaantuneet hulevedet vaikuttavat huonontavasti vastaanottavaan vesistöön sekä mahdollisesti ihmisen terveyteen. Rakennustyömailta sedimenttejä kulkeutuu vastaanottavaan vesistöön ja putkistoihin jotka voivat tukkeutua. Huonosti hoidettuna hulevedet voivat näin ollen aiheuttaa rahallisia menetyksiä. Useita haitta-aineita kulkeutuu kaupungistumisen ja rakentamisen huonontamissa hulevesissä. Haitta-aineiden lähteiden ja kulkeutumisen selvittäminen sekä hulevesien hallinta niiden syntypaikalla edesauttavat haittojen ehkäisyä. Tärkeinä tietoina ovat lisäksi haitta-aineiden käyttäytyminen sadetapahtumien aikana ja sitoutuminen kiintoaineeseen.

Rakentamisen aikainen hulevesien hallinta lähtee jo suunnitteluvaiheesta. Sedimenttien kulkeutumista tulee hallita ja maanpinnan tulisi olla mahdollisimman laajalti peitettynä. Hulevesien hallintajärjestelmien ylläpito on tärkeää. Rakennustyömailla hulevesihaittoja hallitaan parhailla käyttökelpoisilla menetelmillä, jotka perustuvat suodattamiseen ja laskeuttamiseen. Hulevesien monitorointi on haastavaa sillä niiden haitta-ainepitoisuudet ja virtaamamäärät vaihtelevat. Rakennustyömaiden tarkastaminen on olennaista hulevesien hallinnan toimivuuden varmistamiseksi. Hulevesien hallinta on tärkeää päätöksenteossa ja siinä on mukana monia sidosryhmiä.

Tämän työn tarkoituksena oli tutkia rakentamisen aikaisia hulevesiä. Mahdollisia haitta-aineita kartoitettiin hulevesinäytteistä sekä maastokäynneillä etsittiin tarkastelukohteita tarkastusohjetta varten. Tarkastelukohteena oli Vuores Tampereella, josta saatuja havaintoja analysoitiin myös laajemmassa kontekstissa. Haitta-ainepitoisuudet olivat kohonneet alueen rakentumisen myötä ja tämän tutkimuksen aikana ne olivat koholla erityisesti sateen aikana ja kiintoaineeseen sitoutuneena. Myös sulfaattipitoisuudet olivat koholla osassa Vuoresta. Rakennustyömailla havainnoitiin tilaa olevan vähän ja sen vuoksi alueelliset hulevesien hallintajärjestelmät ovat tärkeitä. Vuoreksessa on jo nyt hyvin hoidettu kiintoaineen pidätystä mutta huomiota tulee silti kiinnittää erityisesti sedimentteihin ja eroosiosuojaukseen erityisesti sateiden aikana. Myös talvi, lumet sekä lumien sulaminen ovat merkityksellisiä. Lisäksi valmiiden systeemien, kuten ojien, kunnostamiseen on syytä panostaa. Tämän työn perusteella hulevesien hallintaa rakennustyömailla auttaisivat tarkastuskäynnit joiden etenemisestä on luotu protokolla.

PREFACE

The topic for this thesis emerged from the needs of the City of Tampere and was executed with cooperation of the City of Tampere, Tampere University of Technology and me, the thesis author. I would like to thank The Tukisäätiö of Tampere University of Technology and Maa- ja vesitekniikan tuki ry for enabling this thesis financially. I would also like to thank my examiner Professor Jukka Rintala from Tampere University of Technology for his advices and thorough review of my writing, and Maria Åkerman from the City of Tampere for making this subject possible for me, instructing me and supporting me through this whole process. Special thanks belong to Nora Sillanpää from Aalto University whose valuable advices aided to focus this thesis on the right objects.

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I finally conquered my cave of ordeals, for the second time.

Tampere, 28.7.2015

Elina Teuho

TABLE OF CONTENTS

LIST OF DEFINITIONS AND ABBREVIATIONS

Dry period	A period when there is no precipitation.
Permanently wet pond/pool	A level of water, which does not drain out from the depression where it is located.
Rain event	A period when there is precipitation.
Runoff	Water, that flows over surfaces gravitationally and is not infiltrated.
Sediments	In this thesis sediments signify mainly the loose soil that is transported by stormwater runoff.
Stormwater pond	A pond, which detains stormwater runoff and settles particulate matter. May or may not contain a permanently wet pool.
Stormwater runoff	Runoff, which occurs in urbanized area.
Stream	A natural route, in which water flows.

Al	Aluminum
As	Arsenic
BMP	Best management practice
BOD	Biological oxygen demand
BOD_5	Biological oxygen demand of five days
BOD_{20}	Biological oxygen demand of 20 days
Ca	Calcium
Cd	Cadmium
Cl^-	Chloride
Co	Cobalt
COD	Chemical oxygen demand
COD_{Cr}	Chemical oxygen demand with dichromate method
COD_{Mn}	Chemical oxygen demand with permanganate
$COD_{Cr\ sol}$	Soluble chemical oxygen demand with dichromate method
$COD_{Cr\ tot}$	Total chemical oxygen demand with dichromate method
Cr	Chromium
Cu	Copper
EMC	Event mean concentration
Fe	Iron
GIS	The geographic information system
Hg	Mercury
KVVY	Kokemäenjoen vesistön vesiensuojeluyhdistys ry
Mg	Magnesium
Mn	Manganese
NH_4^+	Ammonium
NH_4^+ –N	Ammonium nitrogen
Ni	Nickel
NO_2^-	Nitrite
NO_2^- –N	Nitrite nitrogen
NO_3^-	Nitrate
NO_3^- –N	Nitrate nitrogen
PAH	Polycyclic aromatic hydrocarbon

PAM	Polyacryle amide
Pb	Lead
PM	Particulate matter
PO_4^{3-}	Phosphate
PO_4^{3-} –P	Phosphate phosphorus
SO_4^{2-}	Sulfate
SS	Suspended solid
SWMM	Storm water management model
SWPPP	Stormwater runoff pollution prevention plan
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TS	Total solid
TSS	Total suspended solid
TUT	Tampere University of Technology
VSS	Volatile suspended solid
Zn	Zinc

1. INTRODUCTION

Different urban land uses can be categorized as residential, commercial, industrial, highway, educational institutions, parks and open spaces, and all of these accumulate pollutant buildup. Pollutants can be transported from urban land surfaces onwards above ground with surface runoff, scouring and erosion, causing surface water degradation. Pollutants can also be transported by infiltration causing ground water degradation. Water degradation can lead to detrimental effects on organisms and human health. (Tsihrintzis and Hamid 1997.) Runoff that is affected by urbanization creates a quality based threat to receiving waterbodies in all seasons (Valtanen et al. 2014a).

Stormwater runoff is considered to be a non-point pollution in urban areas (Kaufman 2000). Whereas the point-source pollution controls are implemented, the non-point source pollution is complicated to mitigate and even to discover, which is why the non-point source pollution is an increasing cause of receiving water degradation. (Zhu et al. 2012.) Stormwater runoff from construction sites are classified as a non-point source pollution (Harbor 1999). Stormwater runoff depends highly on local conditions. For example, catchment characteristics affect greatly first-flush. Stormwater runoff can be characterized based on its quantity and quality by monitoring and modeling. Monitoring and data collection methods depend on local conditions and the available time and money. It is better to have little than no information and to obtain a small amount of reliable information compared to abundance of uncertain information. Different monitoring objectives depend on their application, because monitoring might be needed for the decision to build a new treatment system, determination of a best management practice (BMP) efficiency or the evaluation of the impact of stormwater runoff on water and hydrological quality. (Barbosa et al. 2012.)

Stormwater runoff management is affected by geophysical, social, economic and technical factors. The geophysical factors include climate, land use, soil, catchment and topography. From the geophysical factors, climate means mostly precipitation and catchment means the space available for stormwater solutions. The social factors are connected with educational programs and the economic factors or expenses should be included at an early stage in decision making. The technical factors or technology should be carefully considered, because all the BMP implementations do not share similar desired results based on local conditions. (Barbosa et al. 2012.)

Urbanization means more impervious surfaces causing more runoff and less infiltration of precipitated water (Zhu et al. 2012). Actually, the highest level of urbanization has been found to induce the largest annual runoff volumes (Valtanen et al. 2014b). The stormwater runoff volumes increased by urbanization are even suggested to be utilized as a water source (Walsh et al. 2012).

Stormwater runoff can be treated to mitigate the detrimental effects of pollutants. The source control of stormwater runoff, which means treating it on-site, aims to target the pollutants before they enter in the drainage system. The drainage system can be of natural type or sewers. Stormwater runoff can be treated with structural BMPs like detention/retention/wet ponds, infiltration trenches or basins, sand filters, grass swales and constructed wetlands. Before implementing a BMP certain issues, such as stormwater runoff quantity and quality characteristics, the desirable treatment level and the possibilities to execute the BMP, should be reported. (Barbosa et al. 2012.) It makes a difference if stormwater runoff is directed into natural-like stormwater runoff system instead of conventional stormwater runoff drainage. When the solution is more natural like, the ecological condition of the receiving waterbodies is better. (Walsh et al. 2012.)

Building industry has several impacts on the environment. Besides energy use and greenhouse gas emissions, stormwater runoff is one of the environmental impacts and should be protected against the contaminants during excavation and construction. Environmentally responsible actions in building save money in fewer sanctions, less environmental restoration, better environmental profile and improved chances in tendering. Environmentally the most significant building phase is the initial work or excavation. At construction site sediments and soil piles should be covered until removed or used, the vehicles should not be washed at the vicinity of the site and stormwater runoffs should be collected and settled on site. (Cole 2000.) Efficient drainage and impervious areas increase the velocities and energy content of runoff, which erode ditches and riverbeds. In a construction site, the conditions are almost constantly changing and this might require the changing of erosion control plans along with the construction progress. (Harbor 1999.)

The purpose of this thesis was to create a frame for inspections of construction time runoff management based on theoretical survey, stormwater runoff sampling and observation field trips in Vuores, which is a new development area under construction in Tampere. Stormwater runoff samples were taken to discover which pollutants would emerge from the area. Field observations were done on several occasions to construction sites of varying stages and their surroundings, with the object of discovering improvement needs. Both sampling and field observations were subjected to variations in weather and seasons, including winter. Based on the results, an outline of a protocol was recommended for construction site inspections.

2. BACKGROUND

Stormwater runoff management during construction needs to be explored. Urbanization and cold climate affect hydrology and runoff from urban areas and construction sites. The effect of urbanization on runoff also threatens the quality of receiving waterbodies, the aquatic habitat and public health. Pollutants that reside in and are transported by runoff cause these effects. Construction site is one of the sources of these pollutants.

Several methods can mitigate the construction site induced stormwater runoff detriments. One of these methods is the BMPs. The surveillance and monitoring of construction site runoff is beneficial and helps to control the runoff. The control of stormwater runoff at construction sites begins already in different decision making processes and ends with various inspections after the constructions are finished.

2.1 Hydrological effects of urbanization and cold climates

2.1.1 Hydrology

Urbanization changes catchment hydrology and natural environment (Piro and Carbone 2014), and impervious surfaces are strongly linked to runoff generation (Valtanen et al. 2014b). Additionally, constructed areas, drainage intensity and soil types affect runoff. Catchment areas are complex systems and their conditions in the future cannot be predicted. Impervious surfaces and catchment expansion are part of land development and they induce runoff. The progression of runoff from single rain event has been found to be more rapid at developed area compared to undeveloped area. Urbanization also causes higher peak flows and larger total volume of runoff. The development from rural to medium density area causes distinct difference in flow-frequency curves. High flow rates that occur infrequently increase clearly, and the low flows that occur often decline rapidly. (Guan et al. 2014.) When comparing urban and rural streams, urbanization has been observed to increase the fluctuation of stream flow volumes (Masterson and Bannerman 1994). Furthermore, urbanization decreases catchment lag at warm periods (Sillanpää 2013, p. 206).

Construction work has an effect on hydrology, which changes along with construction phases. Therefore, it is important to study different development phases within a same catchment area. The importance of studies in the same catchment area is emphasized by the fact that catchment areas differ from each other. (Guan et al. 2014.)

The rehabilitating of pre-development hydrology with different options has been studied with modeling. Options for rehabilitation were volume control with vegetated roofs, flow rate control with storage unit and a combination of these two. Both alternatives reduced runoff clearly, but they worked better as a combination. Although these rehabilitation techniques were effective, they did not fully reinstate the pre-development flow conditions. (Guan et al. 2014.)

2.1.2 Stormwater and a cold climate

Besides the runoff from rainfall, runoff originated from melting snow needs to be considered as the cause of receiving water quality degradation (Zhu et al. 2012). In cold climate, the land use intensity, or the level of imperviousness, is implicated to affect stormwater runoff seasonally. Furthermore, in cold climates the effects of urbanization on stormwater runoff depend, besides on seasons, also on weather. While the prediction of stormwater runoff is difficult, under cold climates it can be even harder. Seasons include cold and warm periods and precipitation type depends on the period (Table 1). (Valtanen et al. 2014b.)

Table 1. *Grouping of different seasons in cold and warm periods and the main precipitation type of the season (Valtanen et al. 2014b).*

Period	Precipitation type, mostly	Season	Months
Cold	Snow	Winter	December, January and February
		Spring	March, April and May
Warm	Rainfall	Summer	June, July and August
		Autumn	September, October and November

Global warming affects the runoff originated from melting snow. Global warming induces evapotranspiration causing more snowfall and snowmelt water. Pollutants from the atmosphere can be absorbed into snowfall. After filling impervious surfaces, dust and pollutants are taken onwards by springtime snowmelt. Snowmelt also transports snowmelt agents, usually inorganic chloride (Cl^-), into waterbodies. In springtime, the waterbodies are at a fragile state and pollutant burst, transported by snowmelt, is highly undesirable for them. (Zhu et al. 2012.) Pollutants are observed to be built up into snow (Semadeni-Davies 2006). When snow is un-touched, especially at low development areas, the snow dilutes the pollutants, although at the same time the snow increases pollutant export due to increased runoff generation. Ploughed snow contains abundantly total suspended solids (TSS) and total phosphorus (TP). Winter time pollution would be mitigated if snow is treated and stored properly (Sillanpää 2013, p. 207–208, 210).

Seasons affect the pollutant concentrations in stormwater runoff significantly. For example, snowmelt in the cold period is shown to peak most of the pollutant concentrations. The correlation happens more often with increasing urbanization, but it is not straightforward. Warm season creates the biggest differences between low and high urbanization levels. For example, urbanization induces the seasonal loads of some pollutants in the warm period. High loads are also present in the time of snowmelt, which indicates the pollutants accumulation in snow. Urbanization is discovered to induce metal association with particulate matter (PM), especially in the cold period. Warmer period induces metal dissolvability in a more urbanized area. (Valtanen et al. 2014a.)

Urbanization has been found to cause the spring snowmelt to occur earlier, but urbanization appears not to affect the rate of snowmelt. Urbanization has also been found to increase runoff rates and decrease rain event durations in the summer. (Valtanen et al. 2014b.) The temporal occurrence of the largest runoff has been found to depend on the intensity level of land use. In more urbanized areas, the portion of spring snowmelt is irrelevant to the annual runoff. On the contrary, in the low intensity location spring snowmelt runoff is the major contributor to annual runoff. Thus, the basis for the designs of stormwater runoff management should be carefully considered. One positive effect of a colder climate is the decrease of the urbanization effects on stormwater runoff quantity. Winter conditions may change depending on the year and it is beneficial to study a period of several years to obtain valuable information about the effects of cold climate on stormwater runoff. (Valtanen et al. 2014b.)

Winter, melting snow and salting against slipperiness affect the functionality of stormwater runoff ponds. In winter and spring, retention time and settling can be reduced, stratification might occur, vertical mixing could be poor and metal mobility could be high. Unfortunately, winter time salting might increase the dissolution of metals. Although salting seems to increase the removal efficiency, the salty water is speculated to settle the pollutants in the water column and to release more pure water from the lower layer of the pond. The majority of Cl^- is released during base flow between rain events, and after that, the other pollutants are also released. (Semadeni-Davies 2006.)

2.2 Effects of stormwater runoff from urban areas

Stormwater runoff has a significant effect on stream water quality (Mallin et al. 2009). Stormwater runoff transports pollutants causing exceedances of pollutant water quality criteria, contaminated stream bottom sediment and excessive flow fluctuations. The first two inflict bioaccumulation and toxicity and the last ones induce a poor habitat. Together they all lead to a degraded biological habitat. (Masterson and Bannerman 1994.)

Stormwater runoff carries many pollutants, which harm water quality, stream habitats, stream organism diversity and human health. Certain pollutants may accumulate in stream bottom sediments and some can bioaccumulate. (Masterson and Bannerman 1994.) Construction site sediments in urban runoff cause detriments, which focus not only towards environment, but also on economics as clogged stormwater runoff drains

(Harbor 1999). Construction sites contribute largely on the sediment loads that affect adversely on runoff and hence the receiving waterbodies (Houser and Pruess 2009, Sillanpää 2013, p. 208).

2.2.1 Effects on receiving waterbodies

Urbanization affects the quality parameters of receiving waterbodies detrimentally (Mallin et al. 2009, Masterson and Bannerman 1994). Mallin et al. (2009) characterized the differences of the water quality in urban, suburban and rural streams. Urban area was described with over 20% imperviousness and containing industries and businesses. Suburban areas contained some business and industry but also a little agriculture and had an imperviousness of 10–20%. Below 10% of imperviousness and agriculture and forestry described the rural area. In this case, the concentrations of biological oxygen demand (BOD), phosphate (PO_4^{3-}), TSS and surfactant were discovered most abundantly in urban streams. Furthermore, fecal coliforms were most abundant in urbanized area compared to suburban and rural areas. (Mallin et al. 2009.)

Runoff pollutants have also a biological effect. Crayfish samples from an urban stream have been observed to contain lead (Pb) concentrations as much as 40 times higher as compared to rural stream. Other heavy metals and polycyclic aromatic hydrocarbon (PAH) concentrations have also been discovered to be high in urban crayfish. Furthermore, benthic macroinvertebrate analysis has indicated better condition of rural streams compared to urban ones. In addition, the amount of fish species has been found more abundant in the rural streams compared to urban ones. (Masterson and Bannerman 1994.)

2.2.2 Effects on the ecology of urban stormwater runoff implementations

The aquatic habitat suffers from stress factors like changing flow conditions and pollutants in permanently wet pools, such as stormwater ponds. Furthermore the ability of pollutants to accumulate into bottom sediments also causes stress. Current state of ecological risk assessment research for ponds is based on, for example, either laboratory conditions or biomarkers and bioaccumulation tests in the field, which are not easily, if not at all, applicable to the whole pond ecosystem. (Tixier et al. 2011.)

The ecological quality of a stormwater pond can be studied with bottom sediment toxicity, which is speculated to be induced by heavy metals. The metal concentrations in a pond have been shown to be highest in the pond bottom sediments, the second highest in the pore water and the concentrations of the overlying water are the smallest. When there are several ponds in connection with each other, the sediment toxicity has been found to be highest at the inlet pond at the inlet location. (Tixier et al. 2012.)

2.2.3 Effects on public health

Public health could be threatened by stormwater runoff originated from urban areas. The connection between turbidity levels of treated drinking water and threats to human health is speculated, which is also linked to insufficiently treated stormwater runoff in urbanized areas. The costs of capital investments of potable water treatment and stormwater runoff management are speculated to be similar to yearly costs of waterborne illnesses. (Gaffield et al. 2003.)

Urbanized runoff is associated with the threat of waterborne diseases. Although it should be studied further, the stormwater runoff treatment with various BMPs is beneficial for drinking water treatment and public health. (Gaffield et al. 2003.)

2.3 Stormwater runoff pollutants

2.3.1 Pollutants associated with runoff

Many pollutants are recognized and studied from urban stormwater runoff at urban or road adjacent locations and construction sites (Table 2).

Table 2. *Various pollutants found in urban stormwater runoff at different sites.*

Site	Pollutants recognized and/or parameters analyzed	Reference
Urban	Suspended solids (SS), Heavy metals, Cl^-, Oil and grease, hydrocarbons	Tsihrintzis and Hamid 1997
Urban	TSS, Heavy metals.	Persson and Pettersson 2009
Urban	Cadmium (Cd), Copper (Cu), Pb, Arsenic (As), Chromium (Cr), Mercury (Hg), Nickel (Ni), Zinc (Zn), TSS, Cl^-, pH, Temperature (T), Effluent conductivity, Dissolved oxygen	Semadeni-Davies 2006
Urban	TSS, Chemical oxygen demand (COD), PAH	Masterson and Bannerman 1994
Urban	Grease and oils, TSS, Total nitrogen (TN), Nitrate nitrogen (NO3- -N), Ammonium nitrogen (NH_4^+ -N), TP, Phosphate phosphorus (PO_4^{3-} -P), Total organic carbon (TOC), Fecal coliform bacteria, Biological oxygen demand of five days (BOD_5) and Biological oxygen demand of 20 days (BOD_{20}), Surfactants, Chlorophyll a	Mallin et al. 2009
Urban	BOD_5, COD, TSS, pH, Conductivity	Piro and Carbone 2014
Construction	pH, Color, Turbidity (filtered, unfiltered), TSS, Volatile suspended solids (VSS), Iron (Fe), total and dissolved), Magnesium (Mg), Manganese (Mn), Aluminum (Al), Calcium (Ca), Sulfate (SO_4^{2-}), PO_4^{3-}	Kalainesan et al. 2009
Construction	TSS, Dissolved oxygen, pH, Conductivity, T	Houser and Pruess 2009
Construction	Solids: turbidity, TSS and total solids (TS); Solids-size: D10, D50 and D90 and D<75µm; Nutrients: nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+) and PO_4^{3-}	Cleveland and Fashokun 2006
Construction	SS, Turbidity, Metals, Nutrients, BOD, COD, Bacteria, Conductivity, pH, Alkalinity, Cl^-, PAHs, Phenolics	Gharabaghi et al. 2006
Construction	TSS, TP, TN, Chemical oxygen demand with permanganate (COD_{Mn})	Sillanpää 2013
Highway related	Al, Cd, Cobalt (Co), Cr, Cu, Fe, Mn, Ni, Pb, Zn	Hallberg et al. 2007
Freeway related	16 PAHs, Heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, Zn)	Tixier et al. 2012

2.3.2 Sources of urban runoff pollutants

Stormwater runoff pollutants originate from different sources which rainwater encounters on the way from rainfall to receiving waterbodies (Tsihrintzis and Hamid 1997). Urban surface runoff originates from impervious surfaces and overland flows from roads, parks and construction sites and from groundwater flooding. When runoff is detained/retained in temporary storage in the terrain, the pollutants have time to transform, making it harder to deduce their source. The sources for different pollutants are identified in Table 3 and different routes of stormwater runoff pollutants are identified in Figure 1. (Lundy et al. 2012.)

Table 3. *Sources for various stormwater runoff pollutants (Lundy et al. 2012).*

Pollutant	Sources
Sediments/Contaminated sediments	Construction sites, Highway surfaces
Metals	Amenity and road verge fertilizers, Car/vehicle washing, Atmospheric deposition, Roof surfaces, Highway surfaces, Retail/commercial/trading estates, Building misconnections, Cross-connections in combined sewer systems
Nutrients	Amenity and road verge fertilizers, Car/vehicle washing, Open spaces (e.g. golf courses and gardens), Highway surfaces, Roof surfaces, Building misconnections
Organics	Amenity and road verge fertilizers, Car/vehicle washing, Highway surfaces, Oil storage (e.g. delivery, overflow), Retail/commercial/trading estates, Building misconnections, Cross-connections in combined sewer systems
Fecal indicator organisms	Open spaces (e.g. golf courses and gardens), Highway surfaces, Roof surfaces, Building misconnections, Cross-connections in combined sewer systems
Hydrocarbons	Oil storage (e.g. delivery, overflow)
Pesticides	Amenity and road verge pesticides, Open spaces (e.g. golf courses and gardens)
Herbicides/insecticides	Amenity and road verge pesticides

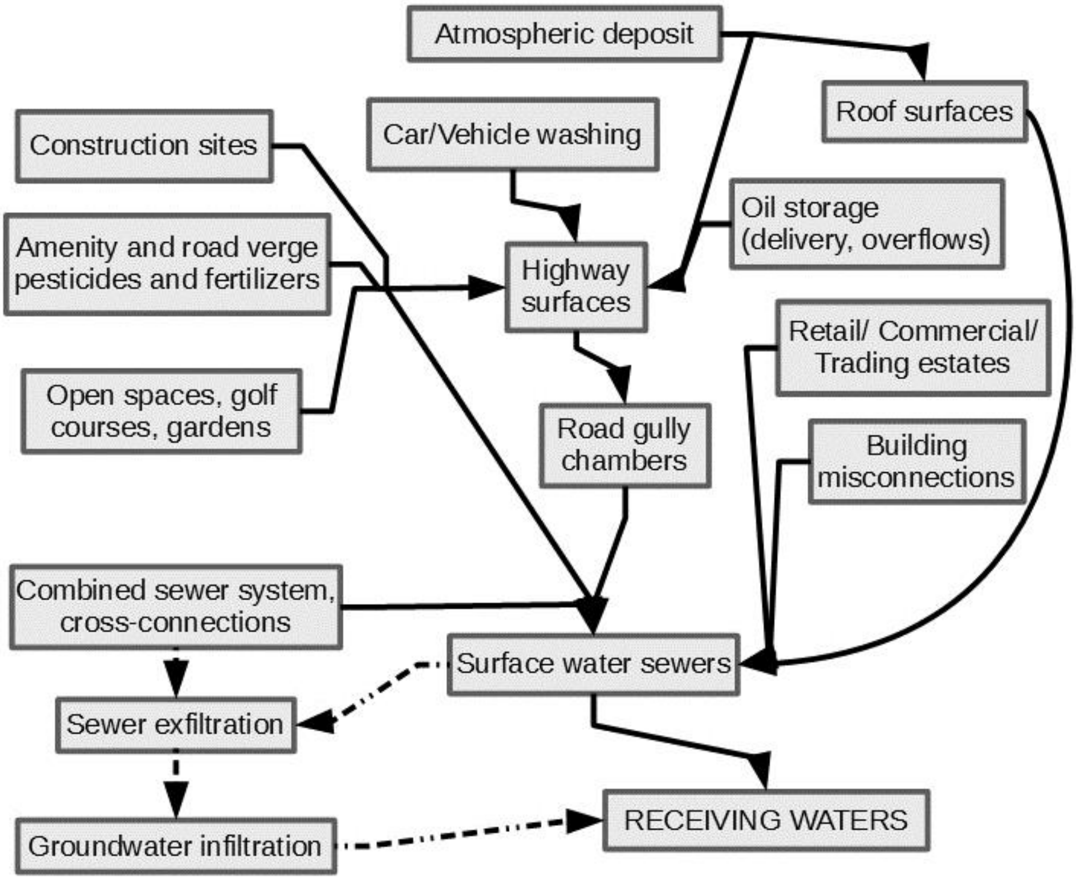

Figure 1. *Different routes of stormwater runoff pollutants entering finally to receiving waterbodies (Modified from Lundy et al. 2012).*

Stormwater runoff pollutant sources, pollutant release, mobilization and transportation should be determined to control pollutants in urban waters. The source control of pollutants is emphasized in stormwater runoff management. (Lundy et al. 2012.)

Information about the transport limitations of pollutants is useful in controlling stormwater runoff pollutants, and the transport limitations are studied regarding TSS. Mass limited transport is observed to be more common compared to flow limited transport, but the flow limited transport system is induced by excavation. (Piro and Carbone 2014.)

2.3.3 Factors affecting urban stormwater runoff pollutant concentrations and their forms

The runoff pollutant concentrations change greatly, so comprehensive and abundant data is necessary to comprehend the real pollutants effects depending on the case (Strecker et al. 2001). For example, urban streams are found to have more elevated PO_4^{3-} levels compared to suburban and rural streams. In addition, NH_4^+, NO_3^- and TN have been found not to depend on whether the stream type is urban or rural stream. (Mallin et al. 2009.)

Peak concentrations in stormwater runoff, for example TSS, total Al, total Mn, total Fe and total PO_4^{3-}, have been found to correlate with rain event peaks (Kalainesan et al. 2009). Both PO_4^{3-} and TP concentrations increase during rain events. On the contrary, the dry period increases the concentrations of TN, grease and oil. Furthermore, NH_4^+ and NO_3^- are not affected by rain events or dry periods. (Mallin et al. 2009.) TSS concentrations are also observed to stay elevated after rain event or snowmelt for many days, and their concentrations seem to lag a few days when comparing outlet and inlet of a stormwater pond. (Semadeni-Davies 2006.) However, this cannot be taken as the TSS behavior in general, because runoff concentrations are unpredictable, but typically TSS concentrations follow rain events. (Gharabaghi et al. 2006.)

The runoff pH affects pollutants. Acidic conditions solute metals (Semadeni-Davies 2006), Ca and PO_4^{3-} (Kalainesan et al. 2009). However, there are some indications that PO_4^{3-} dissolution remains somewhat constant regardless of pH. Possible acidic seeps, with the pH of 5–6.5, located above sedimentation basins could lower the pH of the basin. (Kalainesan et al. 2009.) Stormwater ponds are also assumed to function as a buffer of pH (Semadeni-Davies 2006). The construction sites are shown to increase pH level slightly when comparing to runoff baseline (Houser and Pruess 2009).

Fertilization of stormwater basin slope vegetation could result in PO_4^{3-} and VSS transportation to basin by stormwater runoff. This, in turn, could cause algal growth and high chlorophyll concentrations in a basin. (Kalainesan et al. 2009.)

Relevance of pollutant dissolvability and association to PM is important when designing runoff pollutant controls, because PM is found to transport pollutants. Phosphorus, fecal coliform bacteria, BOD and chlorophyll are found to correlate positively with PM, and NH_4^+, grease and oil negatively. Because several pollutants are connected to PM, the PM related TSS reduction would have benefits like clearer water, healthier benthic stream communities and fewer bacteria, phosphorous and hypoxia. (Mallin et al. 2009.) PAHs are also associated with PM (Clark and Pitt 2012) and for PAH removal, PM removal from stormwater runoff would be beneficial.

Nitrogen in stormwater runoff is mainly dissolved nitrogen, and ammonia is the minor form of nitrogen. An Australian study compared the partition of nitrogen compounds and their concentrations during a rain event and dry period. There were no significant differences in nitrogen concentrations between dry periods and rain events, but the ratio of particulate nitrogen from TN was larger during rain events compared to dry periods. Total dissolved nitrogen from TN was on average 84% and 77 % in dry periods and rain events, respectively. This means that in both conditions, nitrogen in dissolved form was dominant in urban runoff. Nitrogen concentrations in different forms fluctuated rather unrelated to flow conditions. Thus, in order to treat nitrogen from runoff, the treatment system is required to function in high and low flow situations. The nitrogen partition between different forms is observed to vary globally. (Taylor et al. 2005.)

Heavy metals in stormwater runoff and their dissolved and particulate forms have also been studied (Hallberg et al. 2007; Kalainesan et al. 2009; Tixier et al. 2012). A Swedish study observed the behavior of ten metals in highway runoff, the concentrations between dissolved and particulate forms and their seasonal variation being of interest. The forms of metals changed depending on whether it was summer or winter and on which metal was in question. (Hallberg et al. 2007.) Winter time has also been found to possibly increase the metal dissolution (Semadeni-Davies 2006).

2.3.4 Effects of urbanization on stormwater runoff pollutant concentrations and loads

Urbanization increases pollutant concentrations and loads. Along with increasing imperviousness that results from urbanization, the concentrations of TSS, TN, Mn, Co, Ni and Cu are higher. In addition, the pollutant loads of TSS, TP, Al, Mn, Cr, Co, Ni and Cu increase with increasing imperviousness. Pollutant concentrations are affected by imperviousness and land use types, whereas pollutant loads are affected more by impervious surfaces. For some metals, their solubility increases with decreasing imperviousness. (Valtanen et al. 2014a.)

When comparing rural, suburban and urban streams, turbidity is not observed to vary significantly between the stream types. However, TSS concentrations are found to be smallest in suburban streams and surprisingly somewhat similar in urban and rural streams. PO_4^{3-} concentrations are found to correlate positively with the level of urban development and impervious surface, which implies an anthropogenic origin of PO_4^{3-}. The fecal coliform bacteria are found to surpass quality limits on several occasions in not only urban, but also in suburban and rural streams. However, the biggest surplus of fecal bacteria was found in the urban stream. Grease and oils are indicated to peak in the urban stream, but the overall levels remain independent from the stream type. (Mallin et al. 2009.) Besides export rates and pollutant concentrations being levelled up by urbanization, it also affects pollutant concentration fluctuations when a long time period is observed. The fluctuations due to urbanization depend on what is the pollutant and what is the level of imperviousness. (Sillanpää 2013, p. 207.)

Construction sites deteriorate stormwater runoff and disrupt seasonal pollutant patterns. Construction sites have been observed to inflict more recurring event mean concentration (EMC) peaks compared to completely developed area. (Sillanpää 2013, p. 208.) Construction site causes higher TSS concentration levels in the stormwater runoff compared to base flow (Cleveland and Fashokun 2006). Besides TSS and sediments, the construction originated stormwater runoff might be pollutant abundant with sediments, concrete fines, solvents, lubricants and fuels, pesticides and fertilizers. Other toxic pollutants might also be present in stormwater runoff from construction sites like paints, wood preservatives, adhesives and sealants. (Cole 2000.)

2.4 The effect of vegetation on erosion and stormwater pond

2.4.1 Runoff and soil erosion

Stormwater runoff induces erosion, especially from bare soil. Different erosion types are sheet, rill and gully erosions, and also landslides and debris flows are categorized as erosion. The most common erosion type is sheet erosion. In general, the rill erosion is encountered in short-term projects, and rills advance into gullies. Landslides are associated with heavy rainfall and the debris flows with extreme rainfall, and hence they are not very widespread globally. (Wang et al. 2012.)

Two types of soil loss rate have been identified. Type one advance gradually with increasing rainfall intensity until the steady soil loss rate is reached and type two peaks after certain rainfall intensity and then diminishes. Type two soil loss rate results from more slopiness and larger soil bulk density. (Dong et al. 2012.)

2.4.2 The effect of vegetation

Vegetation prevents erosion induced by runoff (Wang et al. 2012), removes nutrients from stormwater runoff (Clark and Pitt 2012) and has a positive role on stormwater pond performance (Persson and Pettersson 2009). In order for vegetation to contribute to nutrient uptake, the stormwater runoff flow rates cannot be large (Clark and Pitt 2012).

Vegetation can be utilized at construction sites for soil stabilization. Retaining the sites natural vegetation or using temporary vegetation diminishes erosion (Table 4). On-site vegetation affects annual runoff and sediment yield, which is loosen from soil and transported by runoff. The annual sediment load for exposed soil without grass is found to be 7456, 3 and 4 as large as the sediment load of natural vegetation covered soil, natural barren land and exposed soil with grass, respectively. Based on these results, the disturbed soils are considered to be prone to erosion compared even to temporary vegetation (Wang et al. 2012.)

Table 4. *The effects of permanent and temporary vegetation on sediment transportation and runoff (Wang et al. 2012).*

	Exposed soil without grass	**Exposed soil with grass**	**Natural barren land**	**Natural vegetation**
Soil origin	Road construction site	Road construction site	Former orange orchad on the spot	
Vegetation	None	Grass, which is recommended to be used in construction sites	Removed	Native shrubs and young trees.
Sediment yield tonnes/ha/year	441.40	106.61	146.91	0.06
Annual runoff (mm/year)	765.85	339.46	443.81	21.39

Vegetation is also a part of bioretention areas, which are used as permanent BMPs after construction is finished. While construction is in progress, it is possible to use a future bioretention area temporarily as a sediment trap. However, it is essential that before a sediment trap is transformed to a bioretention area, it is cleaned properly. (LID Manual for Michigan 2008, p. 144.)

2.5 Managing stormwater runoff at construction sites

2.5.1 Factors affecting detrimentally stormwater runoff from construction sites

Construction includes excavations and soil disturbance, which assist the stormwater runoff induced erosion. Therefore construction activities in an area can cause more abundant TS concentrations in the stormwater runoff, as opposed to the time before construction. (Cleveland and Fashokun 2006; Sillanpää 2013, p. 208.) Erosion control in construction site requires comprehension of soil erosion potential and erosion processes, sedimentation, the sediment transport system and the effects of land use change on catchment hydrology. The degree of erosion control depends, for example, on the erosion potential of the soil and on whether it is dry period or rain event. (Harbor 1999.)

The phases of construction can be divided in the groups of baseline, active construction and post-construction (Houser and Pruess 2009.) Because the land disturbing phase in active construction induces erosion, the land disturbing phase should be carried out during the dry period. Especially at larger construction sites, phasing construction according to seasonally changing rainfalls is beneficial for erosion control. At small sites, the possible daily patterns of rainfall should indicate the time of day, in which to allocate the timing of soil disturbing tasks. (Kaufman 2000.) For example in a Canadian site, a sediment control plan includes the proper phasing of development of the area in order to prevent erosion (Gharabaghi et al. 2006).

The timing of construction works is considered a fundamental aspect of erosion control, and combined with immediate seeding, the timing decreases erosion. Erosion and runoff generation follow rain event trends, but more intense rainfalls are found to cause more erosion although the runoffs would be somewhat similar. (Wang et al. 2012.)

The active phase of construction induces the highest concentrations of TSS in stormwater runoff. Besides being a sediment source, a construction site might possibly act as sediment storage, which occurs if sediments originate from above a construction site, are detained there and later released to waterbodies downstream. (Houser and Pruess 2009.)

In addition, construction site induced sediments could be more intensively transported when the stormwater runoff drains are installed early on with construction roads. If the stormwater runoff drains are not shielded against runoff from construction sites, the construction waters do not stay on the site. This also creates a severe issue of clogged stormwater drainage and results in additional maintenance or even damaged drainpipes. (Kaufman 2000.)

2.5.2 Methods to alleviate detrimental stormwater runoff from construction sites

Construction site stormwater runoff can be controlled with different methods. Stormwater runoff controls begin in the development phase. The coverage of exposed soil and erosion prevention include temporary vegetation, runoff velocity and route control, proper design of outlets and on site sediment control. Regular inspections and maintenance are measures to insure proper stormwater runoff management on construction sites.

First, the development and construction of a certain area should be fitted to site conditions. The area should be investigated properly, for example, regarding site geomorphology, soil characteristics and topography. (Harbor 1999.)

Second, exposing bare ground should be avoided. This can be done by taking advantage of vegetation already present on the site, instead of clearing all the roots that secure topsoil. Grading management and construction timing shorten the time of exposure of the bare soil to erosion. In small sites, this could mean clearing the site as late as possible. Phasing the site clearing and some temporary coverage may be required in larger sites. Soil can be covered with plastic coverage or erosion control blankets for small areas and rapid seeding and/or mulching for larger ones. Mulch gives instant protection and seeds later protection. (Harbor 1999.)

Runoff can be controlled also with managing its routes and rates. Runoff can be guided to bypass the construction site with short-term ditches, creating an off-site flow. Dividing the slopes of the terrain, as opposed to having steep and uninterrupted routes for runoff, creates interference into flows. Slope division can be created with intersecting ditches or terraces. The use of open ditches, instead of channels or roughing up channel surface with plants or rocks and check dams, declines the velocities of runoff. Outlets should be designed to prevent erosion. Proper outlets can be accomplished with for example gabions, which are wire baskets filled with rocks, or rip-rap aprons below the outlets. (Harbor 1999.)

Onsite sediment control is an important method of construction time stormwater runoff control. Sediments can be trapped on-site with silt fences, which slowly release the runoff allowing the sediments to settle. Unfortunately, silt fences are easily installed improperly. Hay and straw bale dikes are also used in sediment trapping, but they are prone to fast degradation, and may result in clogging of the inlets of stormwater runoff drains. Ponds and basins also trap sediments and they can be enhanced with the addition of a perforated riser outlet, which is a water conveying structure with holes. (Harbor 1999.)

Regular inspections and maintenance of stormwater runoff controls are methods that are applied throughout the construction. The inspections are needed to insure that the planned sediment control measures are executed, maintained and used properly. (Harbor 1999.) During construction, the on-site stormwater runoff treatment should be preferred (Kang et al. 2013). With on-site erosion control and good maintenance practices, also the off-site sedimentation is decreased (Werts et al. 2013).

2.6 Best management practices for stormwater runoff

A BMP is a device, practice or method for removing, reducing, retarding or preventing targeted stormwater runoff quantity, constituents, pollutants, and contaminants from reaching the receiving waterbodies. The BMP system includes the BMP and any related bypass or overflow applications. The efficiency of a BMP can be determined for, either by itself as a BMP, or for the BMP system including the bypass flows. (Strecker et al. 2001.)

2.6.1 The principals of best management practices to treat stormwater runoff

Stormwater runoff management can intercept stormwater runoff pollutants in three points; after their build-up, during transportation and during infiltration. After pollutant build-up, before transportation, the pollutants can be intercepted by public education, which means educating the stakeholders that encounter stormwater runoff in their work.

Interception of pollutants before transportation can also be done with, for example, street sweeping. Above surface, after or during transportation, pollutants can be intercepted during scouring and erosion. Examples to do this are detention dry ponds, wet detention ponds, retention ponds, artificial marshes, sand filters and oil grit separators. Pollutants can also be intercepted during infiltration with swales, infiltration trenches or basins, porous pavement and recharge basins. (Tsihrintzis and Hamid 1997.)

Pollutant removal principles mainly are based on physical and chemical processes and their applicability to different pollutants. While solids and pollutants with the affinity to PM can be removed by sedimentation and physical filtration, the chemical characteristics are the basis for the removal of colloidal, non-charged and ionic pollutants. Pollutant removal could theoretically utilize freezing and boiling points, but they are not preferred as viable options. Different theoretical methods can also be based on stratification, density associated separation, volatility and solubility. In addition to physical and chemical processes, also biological pollutant removal is possible, for example, with plants. Different pollutants can be removed theoretically by using unit processes (Table 5). For example, filtration in some form is considered as a multipollutant removal process. (Clark and Pitt 2012.)

Table 5. *Theoretical potential of different unit processes for various stormwater runoff pollutants (Modified from Clark and Pitt 2012).*

Pollutant	**Pollutant detail**	**Treatment with**
Solids	> 5-10 µm	Sedimentation
	1-5 µm	Physical filtration
	< 1 µm	Membrane filtration, Chemically-reactive filtration
Nutrients	Ammonia	Ion-exchange, Oxidation and plant uptake
	NO_3^- and NO_2^-	Ion-exchange, Plant uptake
	PO_4^{3-}	Chemically-active media filtration, Plant uptake
Metals	Pb	Chemically-active media filtration, Ion-exchange
	Cu, Zn, Cd	Chemically-active filtration
	Hg	Chemically-active filtration with organic media
Organics and pesticides	Volatile organic compounds	Air stripping, Chemically-active filtration
	PAHs / oil and grease / Dioxin	Chemically-active filtration
	Organic acids and bases	Chemically-active filtration
	Pesticides	Chemically-active filtration
Microorganisms	Cysts and large Pathogens	Physical filtration
	Bacteria	Physical filtration, Organic media (chemically-active) filtration
	Viruses	Chemically-active filtration

Pollutant removal potentials of BMPs can be estimated based on theoretical information. Table 6 informs which unit processes have high or medium/high relative importance regarding particular BMPs, and to which pollutants they are the most applicable. However, the method for BMPs relative importance and pollutant removal potential was not applied to metals. (Scholes et al. 2008.)

Table 6. *The most applicable BMPs to certain unit processes and their highest removal potentials for various stormwater runoff pollutants (Modified from Scholes et al. 2008).*

The unit process	BMPs (high relative importance)	BMPs (medium/high relative importance)	Highest potentials for pollutant removal[1]
Adsorption to substrate	Porous paving, Infiltration basin	Filter drain, Soakaway, Infiltration trench, Constructed wetland with subsurface flow	PO_4^{3-}
Settling	Infiltration basin.	Sedimentation tank, Detention basin, Lagoons	TSS, PO_4^{3-}, Faecal coliforms
Microbial degradation	Infiltration basin, Constructed wetlands with subsurface flow,	[2]	[3]
Filtration	Porous asphalt, Porous paving	Soakaways, Infiltration trench, Infiltration basin, Constructed wetland with subsurface flow	TSS, PO_4^{3-}, Faecal coliforms
Plant uptake	[4]	Constructed wetland with subsurface flow	NO3-, PO43-

[1] In the pollutant column there is no BOD or COD, which had the relative importance of low, low/medium or medium with all of these removal mechanisms.
[2] There were no BMPs with medium/high relative importance with microbial degradation, but there were BMPs with medium relative importance.
[3] There was only low or medium level of removal potentials for microbial degradation.
[4] There were no BMPs with high relative importance with plant uptake.

Some of the existing BMPs are listed in Table 6 and in Figure 2. Besides these BMPs, also dry wells, grass swales, artificial marshes, recharge basins, sand filters and oil/grit separators (Tsihrintzis and Hamid 1997) sand filters and dry detention (Strecker et al. 2001) are considered as BMPs.

The suitable BMPs chosen for construction activities alleviate the stress of construction site stormwater runoff to the receiving waterbodies. However, the amount of BMP effectiveness studies about sediments is scarce. (Houser and Pruess 2009.) Construction site requires temporary BMPs instead of permanent ones (Cleveland and Fashokun 2006). Some of the studied construction site temporary BMP are as described in Table 7.

Table 7. *Temporary BMPs for construction sites.*

BMPs or other erosion control methods used, studied or referred for construction sites	**Reference**
Sedimentation basins	Gharabaghi et al. 2006 Houser and Pruess 2009 Kalainesan et al. 2009 Kaufman 2000
Silt or filter fences	Houser and Pruess 2009 Kalainesan et al. 2009 Kaufman 2000
Erosion control mats	Houser and Pruess 2009 Kalainesan et al. 2009
Inlet protection	Houser and Pruess 2009
Construction phasing	Houser and Pruess 2009 Kaufman 2000
Construction entrances	Houser and Pruess 2009
Temporary and/or permanent seeding	Houser and Pruess 2009 Kaufman 2000
Dams	Cleveland and Fashokun 2006 Kang et al. 2013
Dams used with polyacryle amide (PAM) amendments	Kang et al. 2013
Soil stabilization with grading, access roads and spoil piles	Kaufman 2000
Water management with buffer strips	Kaufman 2000
Natural partially or totally closed sinks in the terrain	Kaufman 2000

2.6.2 The functionality of BMPs

BMPs functionality can be described with its performance and effectiveness. Performance is a measure of how a BMP meets its goals for stormwater runoff treatment, when stormwater runoff flows through, or is processed by a BMP. Performance is also characterized by pollutant removal, effluent quality or the mitigation of urban induced increased flows. Effectiveness is a measure of how well a BMP system meets its goals for all stormwater runoff flows reaching the BMP site, including flow bypasses. (Strecker et al. 2001.)

BMPs can be ranked regarding their pollutant removal potential based on theoretical pollutant removal mechanisms and their applicability to different BMPs (Figure 2). With the described method the BMP reaching the lowest values are assumed to function the best, while highest values indicate the worst functionality. Theoretical ranking of BMPs shows that infiltration basins and constructed wetlands with subsurface flow would have the highest removals of BOD, COD, SS, NO_3^-, PO_4^{3-} and fecal coliforms. (Scholes et al. 2008.)

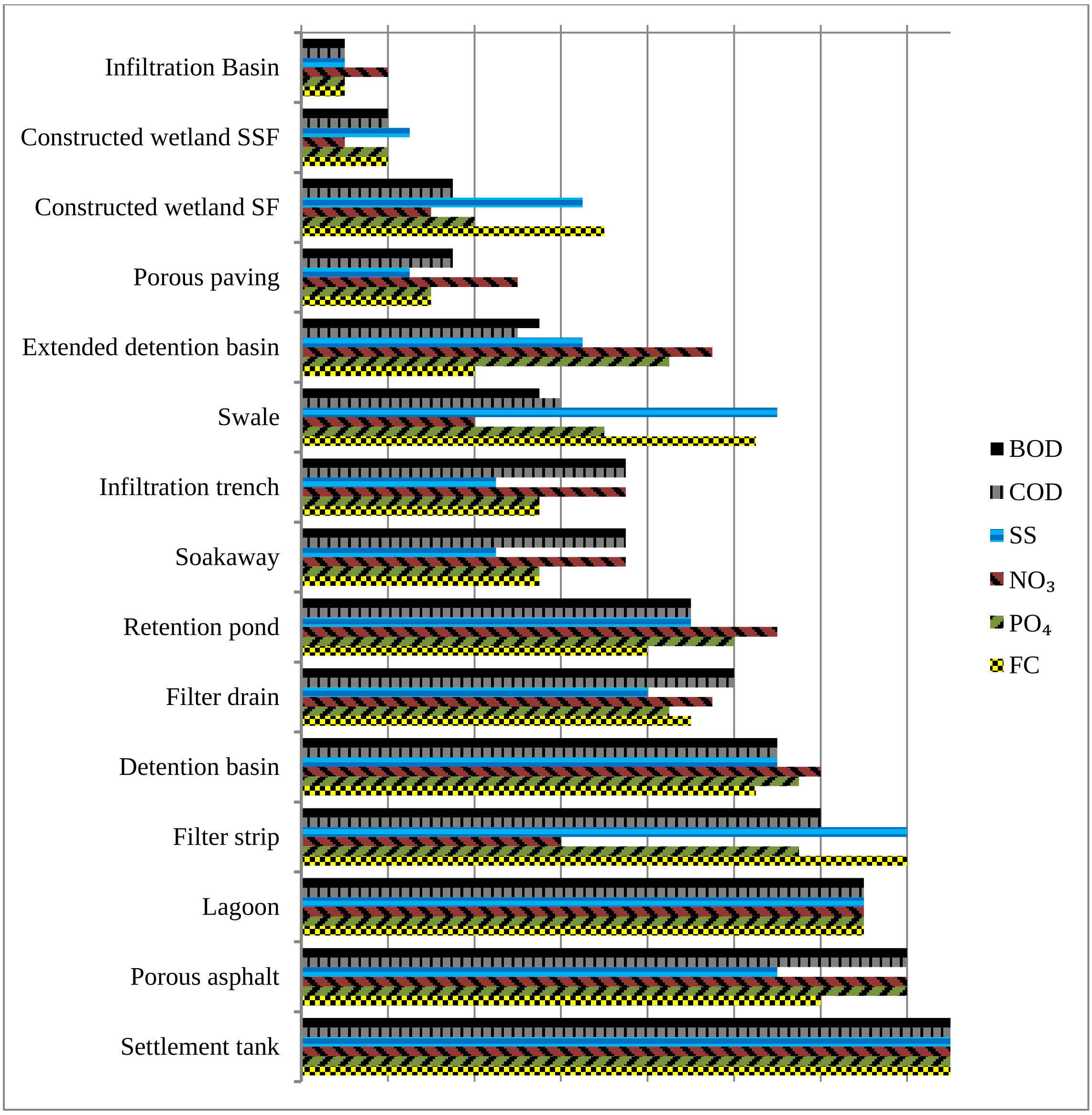

Figure 2. *Ranking of various BMPs according to their removal of BOD, COD, SS, NO_3^-, PO_4^{3-} and fecal coliforms. Shorter bars represent superiority, meaning that infiltration basin functions the best. (Modified from Scholes et al. 2008.)*

As opposed to theoretical calculations (Figure 2), calculations based on real monitored values of TSS resulted in swales performing better and constructed wetlands and extended detention basins not so efficiently. The percentage removal of TSS for different BMPs from different monitoring sets (data gathered by Scholes et al. 2008 from other studies) has been calculated as 80-90% with porous paving, infiltration trench, infiltration basin, swales and constructed wetland with subsurface flow. For retention pond, constructed wetland with surface flow, filter strip and extended detention pond TSS removal was 60–70% and for porous asphalt, TSS removal was just below 60%. (Scholes et al. 2008.)

Various studies enlighten the functionality and performance of BMPs, which however are not unambiguous. The functionality of BMPs not relating to construction sites and BMPs related to construction sites are described here.

BMPs related to urban stormwater sites

Cementitious permeable pavement was studied by straining it with runoff containing PM of sandy silt. It was able to completely remove PM > 300 µm and 50% of < 25 µm. Also the effluent turbidity was lowered by 42–95%. (Sansalone et al. 2012.)

Urban BMP stormwater ponds and wetlands in Sweden have shown a wide range of removal for TSS, Zn, Cu, Pb and Cd (Table 8) (Persson and Pettersson 2009).

Table 8. *The ranges of pollutant removal efficiencies (%) and efficient volume ratio (%) discovered in urban stormwater runoff ponds in Sweden (Modified from Persson and Pettersson 2009).*

	TSS removal (%)	**Zn removal (%)**	**Cu removal (%)**	**Pb removal (%)**	**Cd removal (%)**	**Efficient volume ratio (%)**
Range	38–87	6–84	16–75	6–90	-17–53	33–91

Stormwater pond has been found to improve pollutant removal efficiency in another Swedish study. The improvements were due to biological activity (algae), the lack of ice coverage, low concentrations of Cl^- and warm water throughout the water column. Pollutant removal efficiencies varied along with different rain events. However, on long term observation, an indication of pond possibly acting as a pollutant source was found. (Semadeni-Davies 2006.)

BMPs related to construction sites

Several studies describe the performance of various BMPs at construction sites. In a sedimentation basin located at construction site, the TSS removal was found to be 15% in an American study. When compared to industrial area stormwater runoff, the average construction site sedimentation basin TSS concentrations were higher. The main finding was that although the sedimentation basin was successful in confining the excessive flow volumes, the confinement of particulates did not work well. In addition, the Al concentrations were often high and above water quality recommendations. (Kalainesan et al. 2009.) In fact, it is possible for sedimentation basin to fail and discharge large quantity of runoff and sediment into receiving system (Harbor 1999).

Construction time rock filter dam has been found to improve water quality reducing sediments and PO_4^{3-} to some extent from the stream. Although it was found that TSS removal might not be successful, there were visually observable sediments trapped by the rock filter dam at upstream side. (Cleveland and Fashokun 2006.) In addition, other dam types have been studied as construction site BMPs with multiple rain events and several dams one after another. The multiple rain events lowered the dam performance and with consecutive dams, the sediments were detained the most with the first dam. The PAM amendments with different dams improved the dam performance. Effective PAM amendments were speculated to be less harmful to the environment compared to elevated sediment concentrations. (Kang et al. 2013.)

Several factors affect the performance of BMPs. These are the influent concentration (Gharabaghi et al. 2006; Strecker et al. 2001), BMPs maintenance (Clark and Pitt 2012; Kalainesan et al. 2009; Kang et al. 2013; Sansalone et al. 2012; Werts et al. 2013), clogging (Sansalone et al. 2012), size of permanent pool (Persson and Pettersson 2009; Scholes et al. 2008) and length-to-width ratio (Gharabaghi et al. 2006).

BMP could be characterized wrongly as too inefficient or functioning well. The pollutant removal is low if both influent and effluent concentrations are low (Strecker et al. 2001), which also contradicts the need for a BMP. On the contrary, the treatment system could give an exemplary removal percent even if both the influent and the effluent are pollutant laden. Although the removal efficiency could be high, the pond can still fail to meet the limit values of regulations. (Gharabaghi et al. 2006.) Pollutant concentrations in runoff are usually rather low, but they can vary notably while runoff flow and volume can also fluctuate. (Clark and Pitt 2012.)

Clogging lowers the functionality of a BMP. A dirt cover formed on the surface of, for example, a permeable pavement can cause clogging. Metals, nutrients and solids can clog permeable pavement. (Sansalone et al. 2012.)

The permanent pool of water and its size are implicated to be important in stormwater pond. Pollutant removal increases when permanent pool is large, but gaining a good detention for stormwater runoff, the permanent pool should be small. (Persson and Pettersson 2009.) Furthermore, the adsorption process suffers from permanent pool compared to draining after storm events (Scholes et al. 2008). Stormwater runoff pond could benefit from larger length-to-width ratio. When comparing length-to-width ratios of 8:1 and 2:1, the detention times have been 16.3 h and 12.7 h, sediment removal efficiencies have been 89% and 82% and average outlet EMC of SS have been 37.2 mg/L and 176.6 mg/L, respectively. (Gharabaghi et al. 2006.)

Maintenance of BMPs is important (Werts et al. 2013). For example, maintenance of permeable pavement four times in a year could result to substantial recovery of the permeable pavement performance (Sansalone et al. 2012). When designing sedimentation basins, maintenance such as the volume of sediment and the intervals of sediment dredging need to be planned (Kalainesan et al. 2009). Also check dams should be inspected periodically to improve their performance, because intense storms may damage the dams releasing deposited sediments onwards (Kang et al. 2013). Furthermore, the functionality of BMPs would benefit if they would not need frequent maintenance. Additionally, lack of electrical power dependency would benefit runoff management units. (Clark and Pitt 2012.)

2.7 Surveillance and inspections of stormwater runoff and construction sites

2.7.1 Monitoring the best management practices and receiving waterbodies

BMPs should be monitored to receive results that enable comparisons of BMPs in different locations, but there are distinctions between BMP monitoring studies. Significant differences are found in sampling techniques, analysis methods, catchment information, BMP design information, techniques for efficiency estimation and statistical validation of results. (Strecker et al. 2001.) The BMP performance information is available for example in the International BMP database (Clark and Pitt 2012; Strecker et al. 2001).

BMPs can be monitored with input and output parameters and with control watersheds, which are used in some extent. Monitoring can also describe the state of catchment area before and after BMP installment, if the changes, from other than BMP origin, are recognized. A collection of a wide spread of information for different types of BMPs is vital. (Strecker et al. 2001.) Persson and Pettersson (2009) studied several Swedish stormwater pond monitoring programs with the results of only 18% of them being sufficient regarding pond performance and comparison between sites. 51 stormwater runoff ponds had a monitoring program and 27 of them contained water quality data from field. From the 27, only nine were considered with sufficient information of pond performance and one of these nine was further discarded due to missing data. Altogether 70% of pond monitoring programs were faulty in design when pollutant removal efficiency was the goal. (Persson and Pettersson 2009.)

Proper sampling to obtain reliable information about stormwater runoff

Planning a sampling strategy insures the applicability and comparability of obtained results. An individual samples can detect the pollutant peaks in stormwater runoff, but they can just as easily miss the peak (Kalainesan et al. 2009) and therefore an automatic sampling in short intervals should be preferred (Gharabaghi et al. 2006). When considering time-weighed sampling, there is a possibility that the first-flush caused by rain event is disregarded, even though there is some indication that peak concentrations might last for many hours. Furthermore, when daily averages are used, the peak concentrations can be diminished. (Semadeni-Davies 2006.) Samples taken, for example weekly, describe better the conditions of construction site compared to samples taken after storm events. This way the samples tell more about the site and not just the effect of intensified precipitation. (Houser and Pruess 2009.) Different sampling techniques describe different perspectives and it is essential to define the exact objectives of the monitoring program.

With single value measurements, the representativeness is not good and more appropriate values to be used are EMCs, which are created from a series of individual samples acquired during one rain event. (Göbel et al. 2007.) For the calculation of EMCs and loads, the flow measurements are required. The inflow to a BMP can be modelled, but the model cannot consider the effect of ice to under ice flow. (Semadeni-Davies 2006.) Nevertheless, the runoff concentrations fluctuate, and therefore comprehensive and abundant data is necessary to obtain results that are relevant (Strecker et al. 2001). An example of insufficient measurement is from monitoring programs where the flow was estimated only visually. Flow measurements are essential for pond performance monitoring. To obtain reliable results, monitoring stormwater pond and their pollutant removal efficiency require additional information with flow conditions. Often information about precipitation, catchment area description, pond water depth, pond vegetation and hydraulic efficiency are lacking. (Persson and Pettersson 2009.) Monitoring data can also suffer from errors due to possible poor sample storing, mechanical measurement problems and the effect of winter (Persson and Pettersson 2009).

The samples can be obtained before and after the BMP (Cleveland and Fashokun 2006) or more closely at pond inlet and outlet for BMP performance (Gharabaghi et al. 2006). They can also be collected from the up- and downstream from the construction site to uncover the effects of construction site to water quality. (Gharabaghi et al. 2006.) In general, grab samples are not sufficient to reflect the pollutant removal characteristics of stormwater ponds or other implementations. Grab samples only depict one pollutant concentration at a certain time, even if the samples are taken at inlet and outlet. The use of grab samples is more justifiable in more stable situations than stormwater runoff associated implementations. (Persson and Pettersson 2009.) Samples could be flow weighed composite samples from the duration of an event or many single samples analyzed individually. Latter is more expensive, but reveals the first flush and the pollutant concentration variations. (Barbosa et al. 2012.) All in all, monitoring stormwater runoff ponds in the field is difficult and it could be better to concentrate more intense measurements towards few ponds than having grab samples from several. (Persson and Pettersson 2009.)

Sampling period

To determine stormwater runoff management efficiency, a consistent monitoring program covering all seasons and several years is essential (Sillanpää 2013, p. 209; Valtanen et al. 2014a; Valtanen et al. 2014b). However, in many studies the monitoring period has been one year or less than one year (Table 9).

Table 9. *Duration of some of the stormwater runoff monitoring programs.*

Monitoring period	Reference
September 2004 – August 2005, a year	Kalainesan et al. 2009
A little over seven months	Cleveland and Fashokun 2006
June 2001 – May 2002, a year	Wang et al. 2012
Five months	Gharabaghi et al. 2006
Several programs, from a few months to over a year	Persson and Pettersson 2009

To understand the effects of urbanization on stormwater runoff in cold climates, the short term monitoring is not sufficient. Even the study period of two years has been considered relatively short, because the interference of changing weather conditions should be taken into consideration. (Valtanen et al. 2014b.) In addition, monitoring of a construction site should cover all construction phases (Sillanpää 2013, p. 209).

Processing the stormwater runoff sampling information to obtain reliable results

BMPs pollutant removal efficiencies can be presented in various ways. Some of the methods for estimating removal efficiencies are the percent removal per storm, the in and out total loads and the statistical characterization of in- and outflow concentrations. Comparing three different methods for efficiency estimations with the same initial data from five storms, the pollutant removal percentages could differ 18 percent units from each other. The use of in- and outflow concentration statistical characterization and the log transformation of EMC are recommended. Removal percentages are not a good approach to study BMPs unless, for example, the influent is pollutant abundant, which cannot be guaranteed, because stormwater runoff concentrations and volumes change a lot. (Strecker et al. 2001.) Effluent quality by specific numeric objectives is a better measurement for BMPs than removal percentage (Strecker et al. 2001, Clark and Pitt 2012). Also pollutant mass method is described to be better compared to single in and out concentrations (Persson and Pettersson 2009). In addition, also pollutant exports are suggested to be better criteria to evaluate the effects of pollutants than concentration levels (Sillanpää 2013, p. 208).

2.7.2 Surveillance and inspections of stormwater runoff at construction sites

Stormwater runoff related surveillance at construction site includes visual observations and BMP inspections. Visual inspections can consist of observations about sediments like buried silt fences, sediment leaving from sedimentation basins, other sediment discharges and the state of off-site stormwater outlets. The condition of bare or excavated soil and existing or lacking erosion controls should be visually evaluated at construction sites. The severity of the state of the sediments, erosion control and bare and excavated soil should also be evaluated. In addition, nearby receiving streams or other receiving waterbodies should be inspected for any abnormal sediment transportation from construction sites (Werts et al. 2013), as well as surroundings, like the abundance of small lakes should be noted (Kaufman 2000). A proper documentation during inspections, such as taking photographs, is important (Kaufman 2000).

An effective categorization supports the construction time inspections. Construction site BMPs can be categorized, for example, in three classes (Table 10) regarding slope and soil stabilization and water management. BMPs can be evaluated whether they are properly or improperly installed, or if they lack altogether. For example, a study from United States describes the implementation of BMPs to be poor on construction sites. The slope stabilization is something to pay attention to, because it can be in a poor condition compared to other implementations. (Kaufman 2000.)

Table 10. *Some of construction site BMPs divided in three groups of soil and slope stabilization and water management (Kaufman 2000).*

BMP group	Includes
Slope stabilization	Mulching, seeding, staging
Soil stabilization	Grading, access road, spoil piles
Water management	Buffer strip, filter fence, sediment basin

The violations regarding stormwater runoff management in construction site can also be divided in major and minor concerns. A major concern is a missing stormwater runoff construction permit or other similar document, if required. The minor issues are divided into sub-groups of missing inspection records, BMP violations and violations against water quality. The BMP violations consists of BMPs absence, inadequacy, maintenance failures, sediment nuisance, the absence of erosion/sediment control, significant erosion and failure of implementing final site stabilization. Violations against water quality are discharge to receiving waters, habitat degradations and extreme environmental damage. (Alsharif 2010.)

Construction site changes as the construction work proceeds and therefore the stormwater runoff inspections should be adapted to the changes. The field monitoring program should cover the whole development of the area (Cleveland and Fashokun 2006; Gharabaghi et al. 2006). For example, Ohio EPA has demanded inspections to occur at an active construction sites daily, weekly and with rain events (Houser and Pruess 2009). After rain events of predetermined size, the inspection visits cannot be prolonged longer than two days (Kaufman 2000). The difficulty to predict rain events might complicate the planning of inspections.

When failures occur in stormwater runoff management at construction sites, the reason is often the lack of knowledge about BMPs. It is possible the BMPs are applied in a wrong way due to inadequate information about the soil at the site, hydrology or topography. (Kaufman 2000.) Even if the plans for stormwater runoff management were adequate, a poor or lacking BMP implementation is still possible (Alsharif 2010).

Construction site inspections, education of responsible parties and stakeholders, and enforcing the regulations are significant to improve the state of stormwater management during construction. The defects must be found and the responsible parties need to be guided by improving their knowledge about the subject. The responsible party can be a city, a township, a state agency, a county or a private agency of small or large housing developments. Violations are partly due to lack of communication and information flow. It is found that after updating regulations, the responsible parties may not have the means or resources to gain necessary information. The responsible parties possibly rather pay the penalties than go through the proper procedure, which raises the question of proper punishment for ignoring regulations so it would enhance co-operation. The construction site stormwater runoff permits or comparable documents should be easy to fill out by the applier, which would avert the fact of responsible party not having the time or desire to apply the permit. Enforcing regulations catches more responsible parties, which is good, because then the inspections recognize the type of violation and the responsible party receives instructions to improve construction site stormwater runoff control. Overall, the responsible party has to comprehend the severity of stormwater runoff management. (Alsharif 2010.)

2.8 The main approaches to improve the control of construction site stormwater runoff

2.8.1 Decision making

Decisions about construction time stormwater runoff controls are made in different levels such as political, regional and local levels. In all of them, information of the ramifications and characteristics of stormwater runoff is needed. Information can be obtained from literature, field monitoring and modeling. Sufficient and representative information is necessary in order to avoid extra costs and wasting time. (Barbosa et al. 2012.)

Evaluation of risks from urban stormwater runoff pollutants to receiving waterbodies can be used to aid decision making. Pollutant risk is a combination of the likelihood of occurrence and the level of consequence. The likelihood of occurrence is between very low and very high probability and the level of consequence can be insignificant, minor, significant, damaging or critical. When these are combined the risk of stormwater runoff towards receiving waterbodies is characterized as high, medium or low. In general, the resulting high risks should be attended and medium risks considered if they require remediation. (Lundy et al. 2012.)

2.8.2 Stakeholders

Many stakeholders are related to construction site stormwater runoff management. The stakeholders need to be informed about erosion and sediment movements so they are able to understand the purpose of stormwater runoff management and they are able to function accordingly. Especially erosion control in construction sites requires interdisciplinary information change and collaboration between the stakeholders. (Harbor 1999.)

The stormwater runoff inspectors and predevelopment designers should be required to have professional knowledge in erosion processes. Ideally, an expert would produce ideas how to minimize the risks of erosion at construction sites. (Harbor 1999.) However, the construction site inspections require sufficient human resources, which is often lacking. Granting the inspection authority for local stakeholders could alleviate the situation. (Alsharif 2010.)

2.8.3 Choosing best management practices

When choosing a BMP, it is beneficial to first discover what kind of pollutants and pollutant sources are expected from the site. References of pollutant sources are suggested by land use and the observations from comparable sites. Stormwater runoff management plan and implementations base on the characteristics of stormwater. (Clark and Pitt 2012.) In addition, BMP ranking according to pollutant removal potential could be used as a tool in decision making, but it cannot be used as a basis for the decisions alone as decisions require additional information. (Scholes et al. 2008.) Also cold and warm season differences and impacts affect the design of the implementations of stormwater runoff management (Valtanen et al. 2014a).

Before a BMP is implemented, stormwater runoff quantity and quality, the desirable treatment level and the possibilities to execute the BMP should be analyzed and reported. More investments and maintenance is required with complex BMPs compared to simple implementations. Complex BMPs also require more experience and knowhow from its implementer. (Barbosa et al. 2012.)

2.8.4 Use of geographic information system and modeling stormwater runoff control

The geographic information system (GIS) aids the planning of stormwater runoff management (Alsharif 2010). Besides assessing erosion, GIS is a viable tool to inform decision makers about erosion. However, the data available to GIS should be handled with caution. (Renschler and Harbor 2002.) Satellite imagery and aerial photographs help to identify places of excavation and assess the soil loss potential risks. Recognition of potential risk locations however requires that the sites should be easily identified from the photographs. (Werts et al. 2013.)

Stormwater runoff modeling is emphasized as an important part of its management (Tsihrintzis and Hamid 1997). Modeling runoff is a valid option, because obtaining sufficient data for runoff research is time consuming and requires finances. Models are usually a reasonable choice to predict, assess and manage runoff. One well-known model is storm water management model (SWMM). (Zhu et al. 2012.) SWMM is designed for catchments in developed urban areas (Guan et al. 2014).

The use of erosion models and GIS is not unambiguous, because models depend on the type of inserted initial data. Actually, the proper use of modeling, the data for common users should be available including, for example, information about soils, climate, land use and topography. (Renschler and Harbor 2002.) Furthermore, modeling soil erosion is beneficial when creating regulations about construction site erosion controls. (Renschler and Harbor 2002.)

2.8.5 Recommendations to improve stormwater runoff management

Recommendations regarding construction time stormwater runoff management begins at an early development level and covers the construction industry, inspections and BMPs. Economic incentives offered to the developer would enable efficient erosion control in construction sites. (Harbor 1999). Beside incentives, the legal enforcements and site soil sampling required by regulations would benefit the erosion control. (Kaufman 2000.)

The construction industry works to obtain economical profit but erosion and sediment control are not always seen profitable, which is why regulatory requirements should be applied. National regulation level is more effective over local regulations, because it produces minimum requirements and is not run down by local governments. However, the development of national regulations is slow compared to local ones. (Harbor 1999.) In order for water quality and the condition of environment to improve, actions should be implemented towards construction sites, including legislative actions, guidance for stormwater runoff management and environmental permits. (Sillanpää 2013, p. 210.)

The design and sizing of stormwater ponds and wetlands needs further research (Persson and Pettersson 2009) as does sedimentation basins particle removal (Kalainesan et al. 2009). The commercial construction sites, when compared to residential sites, are found to have better erosion control in the foundation/framing construction phase and worse erosion control in the land clearing phase. The reason for the difference between sites should be studied. (Kaufman 2000.)

Communication and sharing research results globally about stormwater runoff pollution is important (Tsihrintzis and Hamid 1997). Global climate change underlines the role of snowmelt runoff as urban non-point source and more research is needed in this field. (Zhu et al. 2012.) In addition, the behavior of soluble metals in runoff in cold climates needs further research (Valtanen et al. 2014a) as does the management of urban runoff in cold seasons (Sillanpää 2013, p. 211). Studies in Finland are also needed, which includes studies about construction sites and EMCs for different pollutants. (Sillanpää 2013, p. 211.)

3. MATERIALS AND METHODS

3.1 Study area of Vuores

Vuores is situated south-southeast of Tampere, at the border of Tampere and Lempäälä in Finland. The region of Vuores is designed to include residential, workplace, public service areas and parks. (Björninen 2010, pp. 3–4.)

The lakes of Särkijärvi in the north, Suolijärvi in the east and Vuoreksenlammi in the west, and a road of Ruskontie in the south surround Vuores. In the Vuores region, there also are the lakes called Koukkujärvi, Virolainen and Pieni-Virolainen.

3.1.1 The terrain and waterbodies in Vuores

In Vuores, there is naturally a thin layer of moraine and at some points exposed bedrock. Low-lying formations, which are associated with lake and ditch surroundings, contain clay or peat soil. Northeast from Koukkujärvi the possibility to build on soil is characterized as difficult, because the soil is peat on a soft layer of cohesion soil. The original vegetation in Vuores, for example around Koukkujärvi, is considered valuable. There are also swamp areas, which act beneficially for the water balance of the region. (Koipijärvi…1998, pp. 3, 5, 7, 16.)

The catchment of Vuores contains many ditches, which are connected to the lakes in and around Vuores. These ditches are Vuoreksenlamminoja, Rimminsuonoja, Rimminkorventien oja, Koukkujärven laskuoja and Virolaisen laskuoja. The northern part of Vuores discharges its waters to Särkijärvi via Vuoreksenlamminoja, Rimminsuonoja and Rimminkorventien oja and other parts of Vuores discharges their waters south to a lake called Koipijärvi. From Koukkujärvi the waters are discharged via Koukkujärven laskuoja and from lakes Virolainen and Pieni Virolainen via Virolaisen laskuoja. Koipijärvi receives waters also from the ditch Myllyoja, which is located at the east side of Koipijärvi and the lake of Merunjärvi, which is located south side of Koipijärvi. From Koipijärvi waters are discharged to the lake of Höytämönjärvi. The catchment area, in which Vuores is situated, is less than 30 km^2. (The City of Tampere 2012, Appendix 5.) Vuores belongs to the catchment of Höytämönjärvi (37.77 km^2), which is part of the catchment of Moisionjoki (87.43 km^2), which in turn belongs to the catchment of Vanajavesi–Pyhäjärvi (2759.16 km^2). This is further a part of Kokemäenjoki main catchment (27046.12 km^2), which is one of the main catchments in Finland and discharges to the Gulf of Botnia, at the west side of Finland. (Ekholm 1993, pp. 13, 59–61.) Vuores is divided in the catchment areas of Virolaisen laskuoja and Koukkujärven laskuoja, which are further divided to seven sub areas north from Ruskontie. (Björninen 2010, pp. 4, 6.)

3.1.2 The development in Vuores

The regional development of Vuores can be seen from aerial photographs from the years between 1946 and 2013 (Figure 3). In 1946, there were mainly forest and some fields in the area of Vuores and no bigger roads apparent in the aerial photograph. Few larger roads were introduced in the area by 1987. From 1987 to 1995, the visual changes were not very noticeable, but by 2011 the development had increased compared to year 1995 with increased road network and a bridge that has been built across Särkijärvi. Much clearing, excavation activities and streets have appeared by 2011. By 2013, the development has further expanded, with clearings gaining area and new excavations and buildings have emerged.

The Vuores development can also be observed from the development of road network (Figure 4). In 2005, the roads resembled road network of rural areas by not having clearly angular characteristics, which are recognized in city blocks. By 2010 there was a bit more roads, but they were still somewhat rural like. By 2014 the road network already resembled more of city block roads with more angular characteristics.

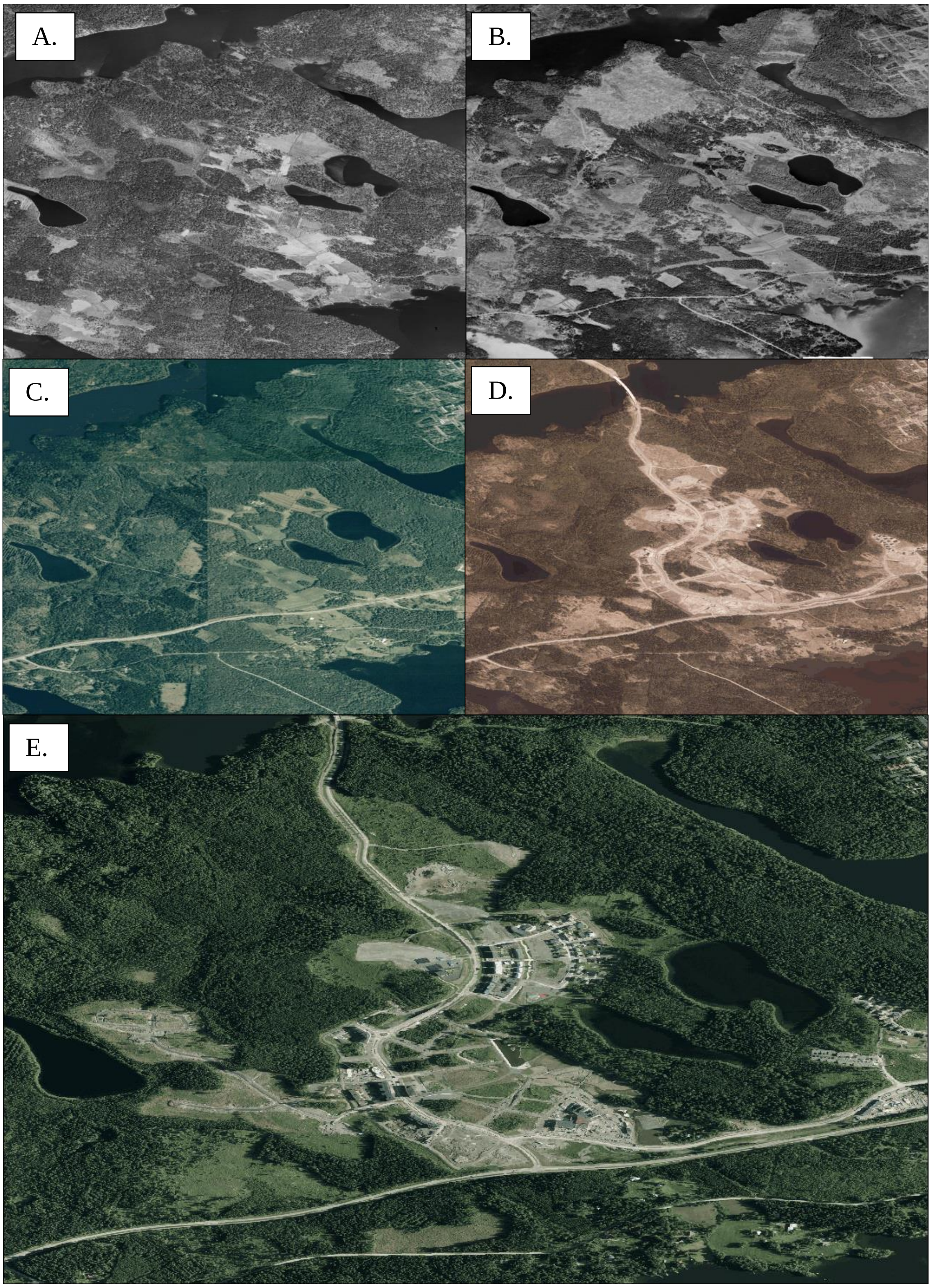

Figure 3. *Aerial photographs of Vuores from the years of A. 1946, B. 1987, C. 1995, D. 2011 and E. 2013, © Tampereen kaupunki, kaupunkimittaus, [29.05.2015]. (The City of Tampere 2015a.)*

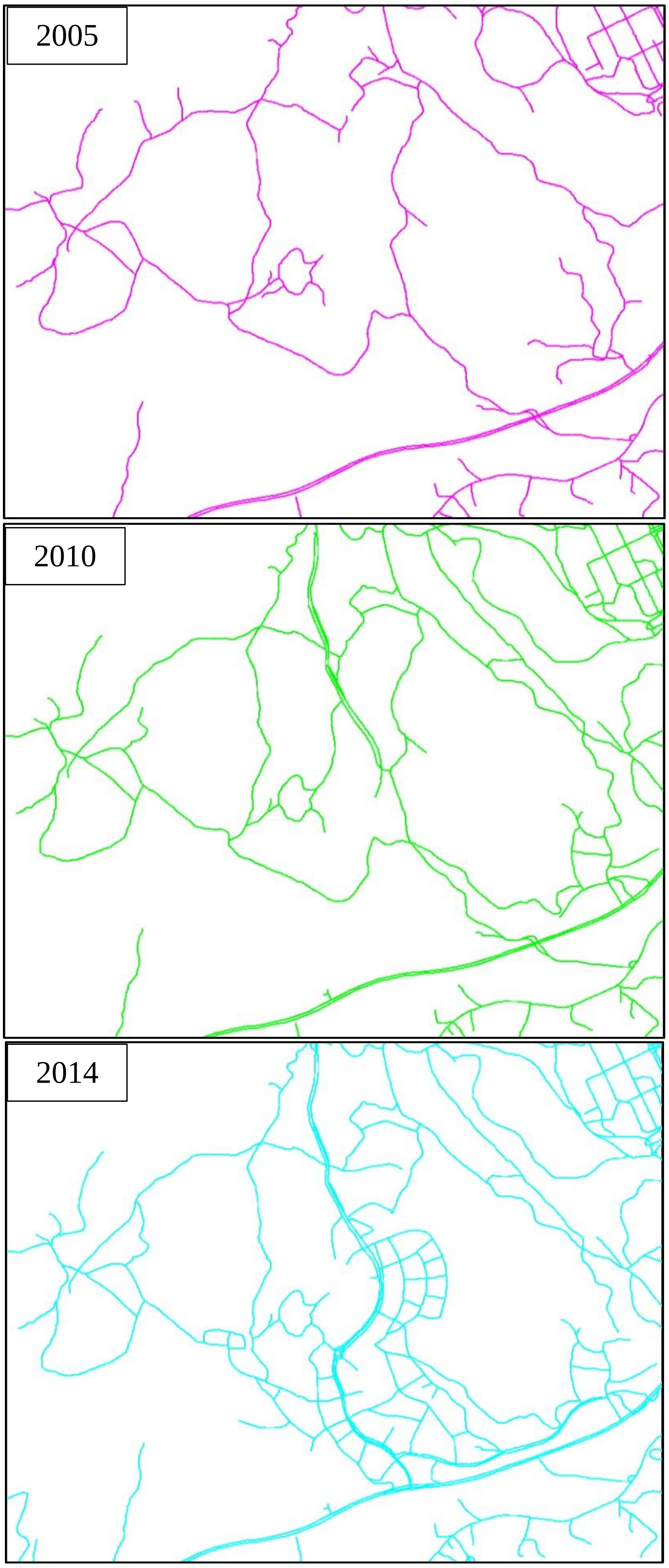

Figure 4. *The development of road network in Vuores region from the years of 2005 © Maanmittauslaitos, 2005 (Topographic Database, National Land Survey of Finland, 2005), 2010 © Maanmittauslaitos, 2010 (Topographic Database, National Land Survey of Finland, 2010) and 2014 © Maanmittauslaitos, 2014 (Topographic Database, National Land Survey of Finland, 2014).*

3.1.3 Management of stormwater runoff in Vuores region

The stormwater runoff management in Vuores is based on the stormwater runoff strategy of the City of Tampere. Although Koipijärvi and Höytämönjärvi are able to dilute the loads, their state has been altered slightly from natural state, and runoff management is required. In the Höytämönjärvi catchment, the nutrient loads discharging to Särkijärvi must not be increased and in the Koipijärvi catchment the runoff need to be detained and its quality improved before discharging to ditches and further to Koipijärvi. (The City of Tampere 2012, p. 16.)

The links between different stormwater runoff management systems and their relation to watercourses and catchment characteristics are essential to understand to control stormwater runoff. Runoff management is designed to be natural like in Vuores. In comparison to traditional methods, the natural methods demand more space and can be more costly. When the Vuores region will be finished, the runoff management will be implemented with flood plains, regulation dams, biodetention/retention areas and stormwater runoff basins. (Björninen 2010, pp. 1–2, 8.)

The stormwater runoff management system in Vuores is designed with modeling and, for example, the hydrological model of Vuores has been realized with SWMM. According to modeling, the flow volumes will be increasing in Vuores due to urbanization. At some parts, the flow is modeled to be four times higher than in natural state. With modeled stormwater runoff management, the flow to Koipijärvi is estimated to increase substantially from natural state to urbanized conditions. Without controls, the discharge to Koipijärvi from Koukkujärven laskuoja is modeled to be almost doubled due to urbanization. According to modeling, the discharge volumes can be clearly alleviated with recommended runoff management methods. Similar patterns are modeled also in regards of Virolaisen laskuoja. In Vuores the soils permeability is low in several places, and it is speculated to create difficulties with infiltration. However, the proposed management methods are speculated to alleviate flow strains and quality detriments of stormwater runoff. (Björninen 2010, pp. 12, 29, 43, 51–52, 54.)

After the construction of Vuores region started, detrimental effects have emerged in the adjacent surface waters (FCG 2014), which occurs although Koipijärvi is able to dilute the effects from construction sites to some extent with flows from other catchment than Vuores (FCG 2014, p. 6). There are also several small lakes situated in the region, which are considered to be threatened by construction site stormwater runoff. (FCG 2009, p. 1.) During construction the stormwater runoff volumes are not expected as large as in finished sites, but the sediment load can be multiple times larger compared to finished sites, and thus stormwater runoff management should concentrate on sediment load decrease. The most probable transporters of sediments in Vuores region are Koukkujärven laskuoja and Virolaisen laskuoja, which both discharge to Koipijärvi. (FCG 2009, pp. 2, 4.) Basic methods to mitigate stormwater runoff stress are erosion protection, filtration and detention/sedimentation (FCG 2009, pp. 4–9; FCG 2014, p. 14) and during initial constructions in Vuores, for example sedimentation basins have been used. During construction, also filtration dams, which remove sediments from runoff, have been used inVuores. The stormwater runoff management forms a large region scale system, which is built gradually along the area of Vuores. Around the central park of Vuores, there are biorerention areas designed to be part of the finished system, and during construction, these unfinished depressions can be used to collect stormwater runoff. (FCG 2014, pp. 5, 6, 15.)

3.2 Methods for sampling, field observations and analyzes

The behavior, effects and consistence of stormwater runoff was studied with two different approaches. Stormwater runoff was sampled in three locations and samples were analyzed to receive water quality results from Vuores. In addition, predetermined construction sites were observed visually during November 2014 – May 2015.

3.2.1 Sampling

The objective of sampling and analyses served the purpose of finding pollutants, which could be found in the construction site related stormwater runoff. Sampling and analyses describe the runoff quality from three different locations adjacent to construction sites in different developing phases (Figure 5, Table 11). The purpose was also to profile construction sites in general and not these particular sites, which is why the results from sampling sites are treated anonymously and they cannot be identified to a certain location. Sampling was divided into different seasons to receive the best possible coverage (Table 12).

Figure 5. *The sampling site near the finished site (A) (top left), the sampling site near the excavation related site (B) (top right) and the sampling site near the excavation/building construction site (C) (bottom). (Teuho 2014a.)*

Table 11. *The descriptions of sampling sites and the related construction and development phase.*

Sampling site	Description of development phase
Finished site (A)	The outlet of a stormwater runoff drainpipe discharging to a bioretention area. The runoff originates from areas where the construction has been finished for a few years before the time of sampling.
Excavation related site (B)	A stormwater runoff sedimentation basin which receives runoff from early phases of construction, the earth moving.
Excavation/building construction site (C)	A stormwater runoff ditch. The runoff is originated from construction sites, construction road and finished street area. The construction sites related to this sampling site are in phases of earth moving works and building construction.

Table 12. *Dates, seasons, overall temperature and the level of precipitation in Vuores during sampling.*

Date of sampling	Season	Outside temperature	Precipitation
16.12.2014	Late fall	-1 … +1 °C	None
17.3.2015	Spring, during or a little while after snow melt	+0.1 … +10 °C	None
6.5.2015	Spring, when ice from ground had melted	~ 12.5 °C	Raining

The samples were taken as close to construction runoff outlets as possible, from outlet pipe, ditch or sedimentation basin describing the construction sites as accurately as possible. However, it was not possible to obtain runoff that originated only from construction sites. For example, the excavation/building construction site (C) samples were from a ditch, which collects runoff from construction areas, construction roads and finished streets.

Stormwater runoff samples were grab samples, which were taken from ditch or pond banks into sampling bottles attached to a sampling stick. The samples were kept in cold boxes during sampling trip, and transported in less than 24 hours into storage at Tampere University of Technology (TUT) at the department of Chemistry and Biotechnology or at Kokemäenjoen vesistön vesiensuojeluyhdistys ry (KVVY). Protocols and standards were utilized with sampling, sample preparation and storing samples (SFS-EN ISO 5667-3 2012; The City of Tampere 2014).

3.2.2 Field observations

Observing the surroundings of construction sites in different construction phases in Vuores was the other main objective of this thesis besides runoff water quality. Observation focused on the notable effects of stormwater runoff and the analysis of the thoughts that emerged from them. Altogether seven construction sites and one sedimentation pond below earth moving works including their surroundings were observed and recorded. The construction observations were limited to the visual evaluations, which could be seen from behind the construction fences, and no construction site was entered. Furthermore, the effects of stormwater runoff on discharging ditches were observed by walking along the outlet ditches, the Virolaisen laskuoja and Koukkujärven laskuoja. The noteworthy issues were documented with a camera and in writing. Altogether six field observation trips were made (Table 13).

Table 13. *The dates of field observation trips and related conditions in Vuores.*

Date of field observation trip	Temperature	Conditions
18.11.2014	*	*
2.12.2014	-2 °C	A bit of snowing
16.1.2015	-0.1 … +1.5 °C	Precipitation in snow, rain and sleet
19.2.2015	+0.5 … +2.5 °C	Foggy, moist, no rain
3.4.2015	*	*
18.5.2015	+8.5 .. +11 °C	*

* Temperatures and conditions were not recorded.

The evaluated field observations were for example:

- Erosion and other sediment related deterioration
- Increased muddiness and turbidity
- The state of discharge and its surroundings below construction sites
- The state of stormwater runoff management or BMPs at construction site whenever they were seen from behind the fences of construction sites
- State of stormwater ponds

3.2.3 Analytical methods

Samples were analyzed for several stormwater runoff parameters. Analyses were done at TUT at the department of Chemistry and Biotechnology and at KVVY. Some parameters were analyzed with field instruments. The parameters analyzed, standards, analysis locations and analytical equipment at TUT were as described in Tables 14 and 15.

Samples for chemical oxygen demand with dichromate method (COD_{Cr}) were stored at TUT in filtered (0.45 µm) and unfiltered forms, some at refrigerator (4 °C) and analyzed within 24 hours from sampling, and others were stored in a freezer (-18 °C) also in filtered and unfiltered forms. Samples for TSS were stored at refrigerator (4 °C) at TUT and analyzed during the day following the sampling. Samples for the analysis of Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-} at TUT were stored in a freezer (-18 °C) and at the day of analysis they were melted and filtered (0.2 µm).

Table 14. *Standards and locations for analyses performed.*

Parameter	Standard	Analysis location
COD_{Cr}	Cuvette test according to standard ISO 6060-1989, DIN 38409-H41-H44, dichromate method	*
TSS	TUT: EN 872:2005, with the exception of analyzed during the day following the sampling, samples 16.12.2014 and 17.03.2015 KVVY: GF/C, SFS-EN 872:2005, samples 6.5.2015	*, **
Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-}	TUT: ISO 10304-1:2007(E), samples 16.12.2014 and 17.03.2015 KVVY: SO_4^{2-} and Cl^- with SFS-EN ISO10304-1:2009 (TL25), NO_3^- -N + nitrite nitrogen (NO_2^- -N) (CFA) with SFS-EN ISO 13395:1997 (TL25) and PO_4^{3-} -P (CFA) with ISO 15681-2:2003, samples 6.5.2015	*, **
Faecal coliforms	SFS 4088, 2001	**
Oxygen	SFS-EN 25813, 1993, modif., samples 6.5.2015	**
TOC	Internal method KVVY LA112, based on SFS-EN 1484:1997, samples 6.5.2015	**
Fe	SFS-EN ISO 11885, 2009 modif.	**
TP, CFA	ISO 15681-2:2003	**
NH_4^+ -N, CFA	Internal method, KVVY LA131	**
TN, CFA	ISO 29441:2010	**
Mn	SFS-EN ISO 11885, 2009 modif.	**
Al	SFS-EN ISO 11885, 2009 modif.	**
Pb	SFS-EN ISO 17294-1;2006 and SFS-EN ISO 17294-2;2005	**
Cd	SFS-EN ISO 17294-1;2006 and SFS-EN ISO 17294-2;2005	**
Co	SFS-EN ISO 11885, 2009 modif. samples 16.12.2014 and 6.5.2015 / SFS-EN ISO 17294-1;2006 and SFS-EN ISO 17294-2;2005, samples 17.3.2015	**
Cr	SFS-EN ISO 11885, 2009 modif.	**
Cu	SFS-EN ISO 11885, 2009 modif.	**
Ni	SFS-EN ISO 11885, 2009 modif.	**
Zn	SFS-EN ISO 11885, 2009 modif., samples 16.12.2014 and 17.03.2015 **/ SFS-EN ISO 11885, 2009 modif. and SFS-EN ISO 15587-2, 2002, samples 6.5.2015	**
Mineral oils	SFS-EN ISO 9377-2:2001	**
PAH	SFS-EN ISO 28540:2011	**

* Analyses performed at TUT
** Analyses performed at KVVY, TL25

Table 15. *Analysis equipment that were used at TUT and in the field.*

Parameter	**Equipment**
T, pH	pH 3210 set 2, WTW, Germany
Conductivity	Cond 3210 set 1, WTW, Germany
Turbidity	Turbidimeter TN-100; Eutech Instruments, Made in Singapore
Total chemical oxygen demand with dichromate method ($COD_{Cr\ tot}$), Soluble chemical oxygen demand with dichromate method ($COD_{Cr\ sol}$)	COD cuvette tests: LCK 414 5-60 mg/L O_2, COD Chemical Oxygen Demand, Hach Lange GMBH, Germany LCK 314 15-150 mg/L O_2, COD Chemical Oxygen Demand, Hach Lange GMBH, Germany
TSS	with GF/A microfiber filters (Whatman™)
Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-}	Ion Chromatography System Thermo Scientific DIONEX ICS-1600 equipped with a DIONEX IonPac As4A-SC RFIC™ 4×250 mm column and a conductivity-based detector. A hydrocarbonate-carbonate solution was used as eluent.

4. RESULTS

4.1 The stormwater quality parameters in Vuores

The general water quality parameters analyzed from the samples were temperature, pH, conductivity, turbidity, COD_{Cr}, TSS, multiple anions and nutrients, fecal coliforms, oxygen, TOC and mineral oils (Table 16). The temperature of runoff was higher at the finished site (A) compared to the excavation related site (B) and the excavation/building construction site (C) with the exception of 6.5.2015 when the sample from the excavation related site (B) had slightly warmer runoff. The finished site (A) also had the highest pH values compared to others. The largest observed values of stormwater runoff parameters were at the finished site (A) and the excavation related site (B). Most of them were from stormwater runoff at the finished site (A), except for $COD_{Cr\ tot}$ and $COD_{Cr\ sol}$, which both had the highest concentrations at the excavation related site (B) 16.12.2014. Furthermore, at the excavation related site (B) there seemed to be the highest concentrations of COD_{Cr} in every sampling time, while the lowest COD_{Cr} concentrations were at the finished site (A). At every sampling site, at the first and second sampling time, the COD_{Cr} was completely in soluble form. At final sampling time, the soluble COD_{Cr} did not account for the whole total COD_{Cr}. Mineral oils were below detection limit through all the samplings.

When comparing all the locations throughout the sampling period, there seemed to be trends for some of the pollutants (Table 16). Conductivity and pH were highest at the finished site (A) and lowest at the excavation related site (B). The Cl^- concentrations were highest at the finished site (A) and lowest at the excavation/building construction site (C). Other parameters did not show a trend.

Table 16. *The quality parameters of stormwater runoff from three locations in Vuores throughout the sampling period. The largest values are underlined. The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

		16.12.2014			17.3.2015			6.5.2015		
Analysis	**Unit**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
T	°C	5.4	3.0	2.8	10.2	6.7	7.3	11.0	12.8	10.4
pH	-	7.0	5.0	5.4	6.2	4.9	5.5	6.5	5.8	5.2
Conductivity	µS/cm	448	120	183	731	177	141	478	135	214
Turbidity	NTU	14.0	13.9	11.0	1.7	7.00	5.3	140.0	4.1	4.7
$COD_{Cr\ tot}$	mg/L	18.0	89.6	58.0	14.3	42.6	45.3	28.6	69.7	44.4
$COD_{Cr\ sol}$	mg/L	17.9	91.8	59.0	14.8	43.0	44.6	15.7	64.4	42.1
TSS	mg/L	7.7	4.2	4.2	< 2	4.2	2.9	470	4.0	3.4
Cl^-	mg/L	8.7	4.6	3.2	12.8	4.8	3.3	5.9	7.1	5.5
TN (CFA)	µg/L	1100	1600	930	1200	1200	790	1300	1100	1200
NH_4^+ -N	µg/L N	19	210	14	8	240	19	190	20	13
NO_3^- -N	mg/L	0.7	0.6	0.4	1.2	0.6	0.4			
NO_3^- -N + NO_2^- -N, CFA	µg/L N							540	490	680
TP	µg/L	20	40	22	5	19	11	170	19	11
PO_4^{3-} -P	mg/L	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.			
PO_4^{3-} -P, CFA	µg/L							89	2	2
SO_4^{2-}	mg/L	153.5	27.6	59.6	237.6	59.3	38.6	18	34	69
Fecal coliforms	pmy/ 100 mL	3	0	32	0	0	0	10	6	< 2
Mineral oils	µg/L	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
TOC	mg/L							29	25	17
Oxygen	mg/L							9.8	11.5	14.5

The metals Fe, Mn, Al, Pb, Cd, Co, Cr, Cu, Ni and Zn were analyzed from stormwater runoff samples from Vuores (Table 17). Most of the largest concentrations were sampled 6.5.2015 from the finished site (A) where most metals peaked considerably, for example Fe (36000 µg/L) and Al (27000 µg/L), while only Ni and Cd concentrations peaked 17.3.2015. Cr was below detection limit otherwise than 6.5.2015 at the finished site (A). Pb, Cd, Co and Cu were below detection limits on several occasions and Ni twice. Besides the elevated concentrations on 6.5.2015 at the finished site (A), the metals did not seem to have trends relating to construction phase.

Table 17. *Metals found in stormwater runoff from three locations in Vuores throughout the sampling period. The largest values are underlined. The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

		16.12.2014			**17.3.2015**			**6.5.2015**		
Analysis	**Unit**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Fe	µg/L	1100	1900	1200	160	860	680	<u>36000</u>	900	590
Mn	µg/L	130	210	140	60	180	110	<u>520</u>	95	170
Al	µg/L	660	1100	1100	220	540	600	<u>27000</u>	520	630
Pb	µg/L	< 0.8	1.2	0.8	< 0.8	< 0.8	< 0.8	<u>11</u>	< 0.8	< 0.8
Cd	µg/L	0.13	< 0.08	0.27	<u>0.4</u>	< 0.08	0.11	< 0.3	< 0.08	0.22
Co	µg/L	< 2	< 2	6.3	1.8	2.1	3.2	<u>20</u>	< 2	6
Cr	µg/L	< 2	< 2	< 2	< 2	< 2	< 2	<u>59</u>	< 2	< 2
Cu	µg/L	7.2	< 5	7.1	6	< 5	< 5	<u>40</u>	< 5	< 5
Ni	µg/L	31	< 4	28	<u>66</u>	6	11	30	< 4	24
Zn	µg/L	53	9.1	78	140	11	30	<u>240</u>	6.6	54

PAHs were discovered from stormwater runoff (Table 18) from Vuores. Runoff from 16.12.2014 did not contain PAHs, while they were found during the other two sampling times. From stormwater runoff on 17.03.2015 at the excavation/building construction site (C) Indeno(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene and Benzo(g,h,i)perylene were found. On 6.5.2015 stormwater runoff at the finished site (A) contained Indeno(1,2,3-cd)pyrene, Benzo(g,h,i)perylene, Phenanthrene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene and Benzo(k)fluoranthene.

Table 18. *PAHs found during two sampling trips in Vuores throughout the sampling period. The locations were the finished site (A) and the excavation/building construction site (C).*

PAH discovered	17.3.2015 C	6.5.2015 A
Indeno(1,2,3-cd)pyrene (ng/L)	34	7.7
Dibenzo(a,h)anthracene (ng/L)	7.4	*
Benzo(g,h,i)perylene (ng/L)	41	32
Phenanthrene (ng/L)	*	54
Fluoranthene (ng/L)	*	120
Pyrene (ng/L)	*	180
Benzo(a)anthracene (ng/L)	*	12
Chrysene (ng/L)	*	70
Benzo(b)fluoranthene (ng/L)	*	35
Benzo(k)fluoranthene (ng/L)	*	10

* No PAH in question was found.

4.2 Field observations

The purpose of the field observations was to investigate the sites in Vuores and to survey adjacent surroundings. The results present both the actual field observations and other possible threats that emerged during field observations. The observations are gathered under different topics such as the use of space at construction sites, the condition and erosion of ditches, piping and piping infrastructure, the BMPs, the effects of snow and winter, littering, the maintenance of the completed systems and other findings. Seven locations with their surroundings were observed six times.

4.2.1 The use of space

The surface areas of construction sites were often observed to be limited, which may limit the construction of basins and ponds on particular sites. No sedimentation basins were noticed on construction sites, only sedimentation basins in joint use for multiple construction sites were discovered. One of the areal issues was the placement of construction time barracks. One was observed to be built almost in a ditch (Figure 6).

Figure 6. *Upcoming construction time barracks and its support ground which are almost entirely built on top of a ditch. Photograph taken 2.12.2014. (Teuho 2014c.)*

During visits to Vuores, some poorly secluded soil piles or rock piles were observed to be placed at the outskirts on the sites (Figure 7). Lack of protective fences or similar solutions would enable the soil to be vulnerable of leaving site with intense rains.

Figure 7. *Soil and rock piles, which are unprotected from rain induced transportation. There is a ditch at the left corner. Photograph taken 03.04.2015. (Teuho 2015c.)*

The efficient use of space was observed to be lacking at construction sites. This issue does not necessarily have relation to stormwater runoff, but it emerged from the observation of, what was believed to be, stormwater runoff cassettes being uninstalled at the middle of the site for at least half a year.

4.2.2 Erosion and condition of ditches

The condition of construction time ditches was observed to be poor, as they looked more like marshland and unfinished ditches (Figure 8).

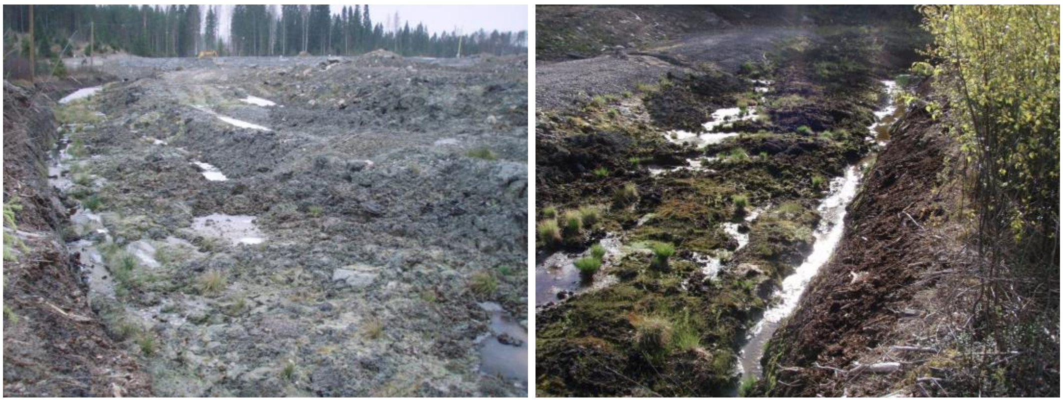

Figure 8. *A ditch built for stormwater runoff (left). Photograph taken 2.12.2014. (Teuho 2014c.) Photograph taken of same location from another perspective (right). Photograph taken 18.5.2015. (Teuho 2015d)*

Erosion was observed at the banks of many ditches near construction sites (Figure 9). Some of these ditches located at finished sites, which brought forward the question of what is proper ditch finishing after construction. Erosion was observed to be severe at some locations and the protective measures were lacking. Crushed stone was used as erosion protection belt or ditch bottom coverage, but it was often questionable as sediments were observed to be transported by stormwater runoff or snowmelt over the crushed stone. Erosion of unstabilized slopes was also observed on top of a sewage pipe.

Figure 9. *Erosion is apparent above the ditch (top left). Photograph taken 2.12.2014. (Teuho 2014c.) The same location after snowmelt with the sediments in the ditch being accumulated (top right). Photograph taken 3.4.2015. (Teuho 2015c.) Signs of erosion wearing out ground over a sewage pipe (bottom left). Photograph taken 18.5.2015. Patterns of sediments transported from uphill to a ditch (bottom right). Photograph taken 18.5.2015. (Teuho 2015d.)*

Observations of pipe installation could indicate improper finalization of the site and possible sediments escaping with runoff (Figure 10). Erosion potential of the ditch banks could be induced if a construction road is used inappropriately, too close to a ditch (Figure 11).

Figure 10. *A pipe installment looking relatively recent (left). Photograph taken 02.12.2014. (Teuho 2014c.) The same location three months later, although the angle is a bit different (right). Photograph taken 03.04.2015. (Teuho 2015c.)*

Figure 11. *Erosion potential created by driving too close to a ditch. Photograph taken 3.4.2015. (Teuho 2015c.)*

4.2.3 Piping and piping infrastructure

A common observation during field trips was the nearly clogged stormwater drain manholes throughout the construction roads (Figure 12). Clogged stormwater drain manholes together with compressed soil of a construction road may create a smooth surface for stormwater runoff flow. The sediments were also found to be transported in the stormwater runoff drains.

Figure 12. *A stormwater drain manhole almost completely clogged (left). A stormwater drain nearly full of sediments (right). Photographs taken 2.12.2014. (Teuho 2014c.)*

4.2.4 Best management practices

The on-site construction time BMPs were not discovered. Only off-site BMP in joint use were discovered. When observing a construction time sedimentation basin, the far corner of sediments above the basin were observed to be transported closer to basin (Figure 13). Future bioretention area was used as entrapment of sediments from a construction site (Figure 14), but the amount of sediments accumulated at the bottom was not large.

Figure 13. *A sedimentation basin at joint use (left). Photograph taken 18.11.2014. (Teuho 2014b.) The same sedimentation basin four and a half months later with sediments closer to basin water level, near the outlet (right). Photograph taken 3.4.2015. (Teuho 2015c.)*

Figure 14. *Sediments from construction site transported to future bioretention area. Photograph taken 18.05.2015. (Teuho 2015d.)*

4.2.5 Winter, snow, and littering

Winter, snow and snowmelt had possible detrimental effects on stormwater runoff near construction sites. The snow at construction sites and roads was often ploughed towards the sides, curbs and on the ditches (Figure 15). As snow melted, piles of soil, sand and litter was revealed underneath. The melting snow also revealed that some of the ditches were used as storage (Figure 16).

Figure 15. *Snow ploughed to a side of a construction road (left). Photograph taken 16.1.2015. (Teuho 2015a.) A view from the same location after snowmelt, when apparent soil, gravel and litter are revealed (right). Photograph taken 3.4.2015. (Teuho 2015c.)*

Figure 16. *Melted snow and stored gravel in a ditch (left). Photograph taken 3.4.2015. A view of the same ditch that is used as storage place as the ditch is located under the snow, gravel and construction supplies (right). Photograph taken 3.4.2015. (Teuho 2015c.)*

Construction induced littering and ditches used as storage areas were common, especially after winter and snowmelt (Figure 17).

Figure 17. *Littering in the ditch near a construction site (top left). Photograph taken 18.5.2015. (Teuho 2015d.) Construction equipment on the left and construction fence on the right in a ditch (top right). Photograph taken 2.12.2014. (Teuho 2014c.) Construction materials stored at ditch banks and the ditch is in the middle, coming from the trees towards the front of the picture (bottom). Photograph taken 19.2.2015. (Teuho 2015b.)*

4.2.6 The maintenance of finished systems

The maintenance of the finished systems was observed to be often questionable. After constructions are completed the surrounding areas should be completed, which includes permanent BMPs and their surroundings. The implementations should be maintained also as the time passes. For example, a finished system, which had accumulated or was transporting sediments, was observed (Figure 18). In this part of the system the water was deduced to be running, which was indicated by the frozen surface, creating a possibility of sediment movement onwards in the ditch system.

Figure 18. *Sediments accumulated in a finished stormwater runoff system (left). Photograph taken 2.12.2014. (Teuho 2014c.) The same stormwater runoff system with a layer of ice that indicates water flow, at least during snowmelt (right). Photograph taken 19.2.2015. (Teuho 2015b.)*

Repairs of a street, which included excavation, caused a ditch to fill up with soil (Figure 19), which was not removed until a later date. A completed stormwater runoff ditch looked eroded and unfinished. Muddy water entered gradually to the completed ditch system (Figure 20). However, there was a filter dam below this particular location.

Figure 19. *Excavations from adjacent street caused the ditch to fill with soil. Photograph taken 02.12.2014. (Teuho 2014c.)*

Figure 20. *A finished stormwater runoff ditch with ice coverage (left). Photograph taken 3.4.2015. A view from the same ditch from a different angle where erosion can be seen (right). Photograph taken 3.4.2015. (Teuho 2015c.)*

The finished slope stabilizations were in questionable state during observations (Figure 21). Erosion was apparent and slope stabilization was not adequate for a site, which has been finished for a longer time. However, rocks below the erosion suggest that sediments would not be transported fluently onwards in the system. At finished site, soil was stabilized with seeding, but stormwater runoff had removed topsoil from several locations (Figure 22).

Figure 21. *Finished slope that has questionable stabilization (left). Erosion at a site that has been finished for quite some time (right). Photographs taken 18.5.2015. (Teuho 2015d.)*

Figure 22. *Seeded topsoil is removed by runoff at a finished site (left). Runoff has removed some topsoil, even when plants, also other than grass, have taken root (right). Photographs taken 18.5.2015. (Teuho 2015d.)*

4.2.7 Other observations

Positive discoveries also emerged during the field observation trips. Upon discussions with construction workers, the positive attitudes about the importance of runoff management during constructions were apparent. However, according to the discussions, the stormwater runoff management does not always function well, and some conversations revealed the lack of knowledge about whether the stormwater runoff management implementation was installed or not. All in all, the construction workers were always ready to discuss about the stormwater runoff management. Another positive finding was that the sedimentation basin in a joint use seemed to be appropriate, although there was no filter dam straight after the basin, but much further down the system. Vegetation was also observed to prevent erosion at some locations. One construction site had a natural stream flowing at one side of the site, and between the site and the stream there were natural trees and vegetation left intact. In addition, construction related ditches and some of the sedimentation basins had vegetation growing at their waterline.

5. DISCUSSION

5.1 Construction time stormwater runoff quality

The region of Vuores has been under development for several years. Some quality parameters of stormwater runoff in Vuores from the present study were compared to the rough estimates of regional averages of stream quality parameters at Tampere region from 1996, when the region was less urbanized (Table 19). The information from 1996 was roughly estimated from the national stream water quality maps, which were originally constructed from sparse sampling density of a single sample from the area of 300 km^2 (Lahermo et al. 1996, p. 27). The development has altered the stormwater runoff quality in Vuores and all the parameters have increased, except pH. For example, electrical conductivity has almost tripled and Al and Fe concentrations have increased drastically from70 µg/L to 3596 µg/L and 0.6 mg/L to 4.8 mg/L respectively. However, a strict comparison of the values in the present study and in 1996 is not possible, due to variants in the stormwater runoff generation, sampling and estimations.

Table 19. *Stormwater runoff quality in the present study (average values) and estimated Tampere region rough values from 1996.*

Parameter	unit	Tampere region [1]	Vuores averages in this study
EC	µS/cm	100	291.8
pH	-	6	5.7
$KMnO_4$	mg/L	30	45.6 [2]
SO_4^{2-}	mg/L	15	77.5
Cl^-	mg/L	5.5	6.2
NO_3^-		0.25	0.6
Al	µg/L	70	3596.7
Fe	mg/L	0.6	4.8
Mn	µg/L	50	179.4
Co	µg/L	0.2	4.4
Ni	µg/L	1.25	21.8
Cr	µg/L	0.3	6.6
Cu	µg/L	1.2	6.7
Zn	µg/L	3.5	69.1
Cd	µg/L	<0.02	0.1
Pb	µg/L	0.15	1.4

[1]Lahermo et al. 1996, pp. 31–33, 36, 37, 40, 41, 44, 49, 50, 74, 75, 80, 82–88, 91, 92, 94–97, 103, 104.

[2] This was COD_{Cr}.

Some of the stormwater runoff parameter concentrations were compared to the guidelines from The Stockholm Vatten (2001) for stormwater runoff, The Riktvärdesgruppen (2009) for lakes and sea, Government Decree (2011) for harmful substances for aquatic environment and Mannio et al. (2011) for hazardous industrial and household chemicals in the aquatic environment (Appendix 1). The results do not represent the overall stormwater quality in Vuores, because the samples were only grab samples, they were taken thrice and only one sample was obtained per trip and construction phase.

5.1.1 The general stormwater runoff quality parameters

The present results show that construction phases, rainfall and seasons affect some of the general water quality parameters (Figure 23). The rain event induced the higher levels of turbidity, TSS, TP and Cl^- and the TSS and TP surpassed the guidelines. The effect of the rain on stormwater parameters was only observed at the finished site (A), but the surface runoff generation induced by the rain event was observed only there, and runoff generation had not yet begun at the other sites at the time of the sampling. The stormwater runoff TSS concentrations were often low (Table 16), which could be due to the dry period, because in general the construction sites produce a great abundance of sediments. The rain event increased PM related parameter concentrations (Figure 23), which is similar to previous findings (for example, Gharabaghi et al. 2006; Kalainesan et al. 2009; Mallin et al. 2009). PO_4^{3-} was discovered only on 6.5.2015, which could relate to the rain event. However, the analysis methods at TUT and KVVY for PO_4^{3-} were different; At TUT the analyzed PO_4^{3-} was soluble PO_4^{3-} with the detection limit of 0.1 mg/L and at KVVY it was total PO_4^{3-} with a lower detection limit. It was also discovered that the rain event did not affect TN and NO_3^- concentrations in stormwater runoff, while their percentual partitions varied throughout the study period and independent of location, as the main fraction of TN was NO_3^-. Nitrogen concentrations have been shown earlier not to relate to rain events (Taylor et al. 2005). This seems to be the case also in the results from Vuores.

The finished construction site (A) was indicated to raise conductivity, pH and Cl^- concentration slightly, where also SO_4^{2-} concentrations were higher compared to the excavation related site (B) and the excavation/building construction site (C). TN surpassed or was near the guidelines often; especially at the finished site (A) and the excavation related site (B). The TOC concentrations were highest at the finished site (A), second highest at the excavation related site (B) and lowest at the excavation/building construction site (C). In a more comprehensive study, TOC concentrations correlated negatively with the levels of development and imperviousness (Mallin et al. 2009). However, TOC concentrations have also been found to not correlate with imperviousness, although urbanization has been found to increase TOC export (Valtanen et al. 2014a).

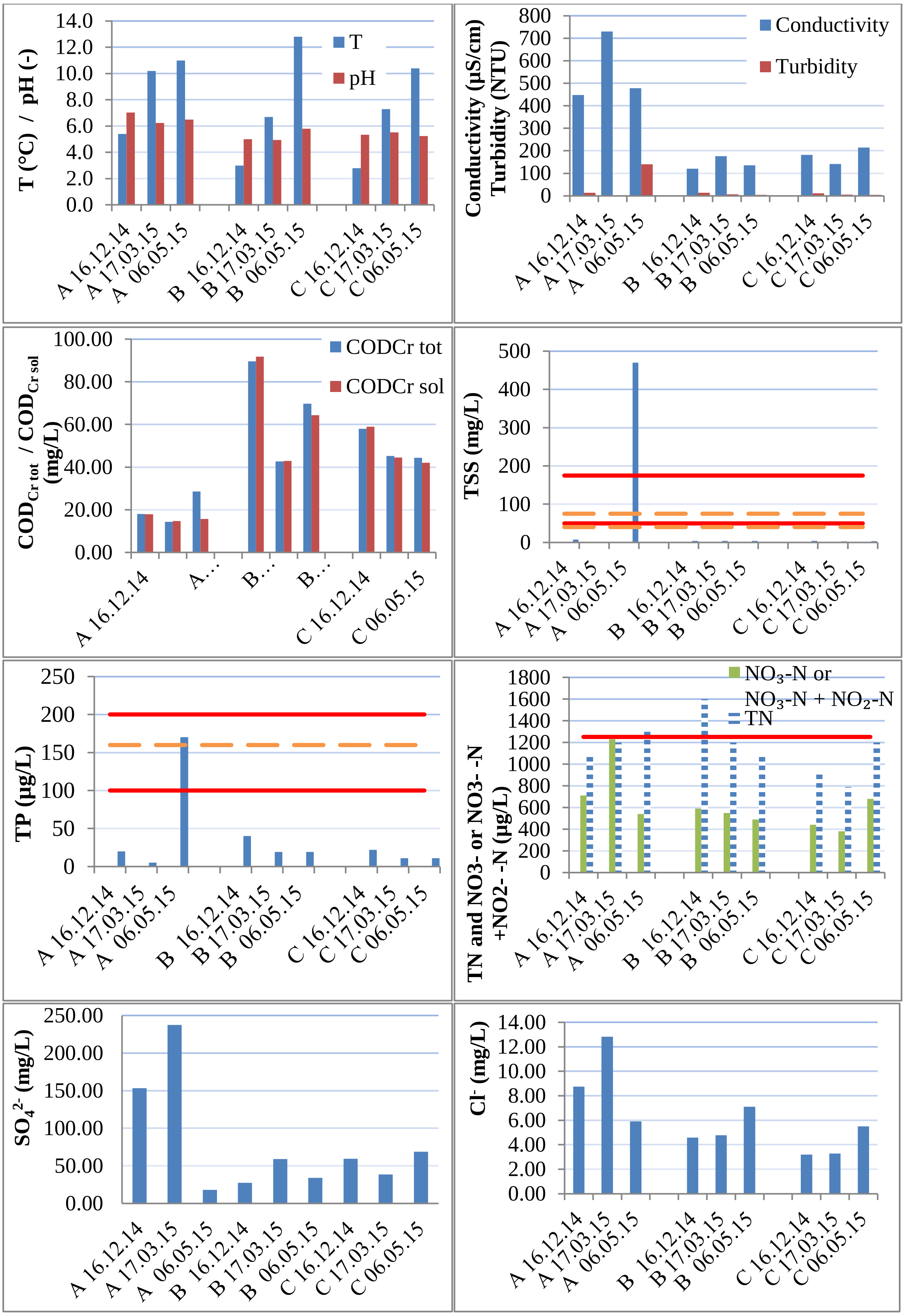

Figure 23. *General water quality parameters in stormwater runoff in different construction sites and seasons. TSS, TP and TN are applied with quality limits, which are represented with continuous (Stockholm Vatten 2001) and dashed lines (Riktvärdesgrubben 2009). The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

SO_4^{2-} and Cl^- concentrations were higher at the finished location (A) compared to the excavation related site (B) and the excavation/building construction site (C). Cl^- could indicate salting used in the prevention of slipperiness during winter. However, using salt during winter varies depending on the location and in Tampere salting is not much used (Åkerman 2015).

Sulfate

SO_4^{2-} was found in abundance from especially at the finished location (A). This, however, has already been recognized as a local issue in Vuores (FCG 2014). SO_4^{2-} belongs to the soil's sulfur cycle (Figure 24), which consists of transformations of SO_4^{2-}, organic sulfur, sulfide and elemental sulfur. SO_4^{2-} may originate from several sources and transformations and it leaves from the cycle via transformations, adsorption to clays or by leaching with water. (Brady 1990, p. 343.)

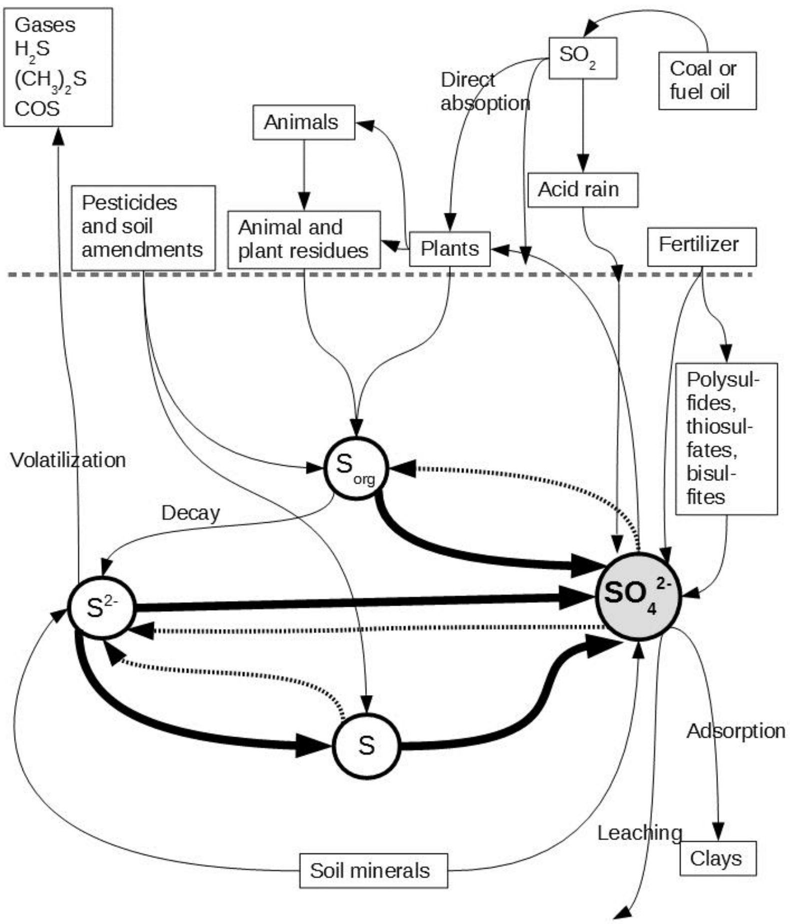

Figure 24. *Sulfur cycle in soil. Sulfur sources to soil are from pesticides, soil amendments, animals, plants, atmospherical residue, fertilizers and soil minerals. SO_4^{2-} is transformed from fertilizers, organic sulfur, elemental sulfur, sulfide, acid rain and soil minerals, and further adsorbed to clays and leached with water. The bold arrows depict oxidation and dotted arrows depict reduction in soils sulfur cycle. (Modified from Brady 1990, p. 343.)*

Natural deposits of sulfur can be found in the volcanic sulfur deposits, pyrites and in elemental sulfur deposits (Meyer 1977, p. 131–133). The major inputs of available soil sulfur, that is SO_4^{2-}, are commercial fertilizer, soil organic matter, rain, crop residues, manures and sulfur-bearing minerals. Major outputs are crop removal and leaching. Outputs of sulfur are also erosion loss, volatilization to atmosphere and transformations back to soil organic matter. (Brady, N. 1990, pp. 347.)

Most common mineral forms of sulfur are sulfide (S_2^-) and SO_4^{2-}. In soil the organic fraction of sulfur is larger compared to the inorganic form, which is soluble and available to plants. SO_4^{2-} is formed when sulfur compounds are oxidized, which in soils is mainly contributed by biochemical and microbial activity and the process decreases the soil pH. The range for pH is roughly from two to nine for sulfur compound oxidization. SO_4^{2-} is not stable when the conditions are anaerobic. When clays in soil have considerable amount of Fe, Al and kaolinite, they are also a viable source of sulfur. This happens above all at low pH and with anion exchange. (Brady 1990, pp. 340–345.) During rain event, Fe and Al were found in abundance at the finished site (A) as was SO_4^{2-}.

SO_4^{2-} leaches with water from the soil, especially in the humid regions. SO_4^{2-} is retented in soil in smaller quantities compared to PO_4^{3-} and only a small amount of SO_4^{2-} is usually retented in most soils. SO_4^{2-} leaches more easily from topsoil compared to subsoil due to the location of Fe and Al oxides. (Brady, N. 1990, pp. 346–347.) In sandy soil SO_4^{2-} leaches easily, and when the area is arid or soil has inadequate water penetration, the SO_4^{2-} accumulates. (Meyer 1977, p. 263.)

5.1.2 Metals in stormwater runoff

Metals in stormwater runoff had higher concentrations during the rain event at the finished site (A) (Figures 25 and 26). Again, the notion about the development between the rain event and the generation of surface runoff is the probable cause. The increase of metal concentration during the rain event indicates metal association with PM. Several metals were above guidelines, such as Pb and Cr during the rain event. Cd, Ni and Zn were independent of the rain event. Metals in the current study were associated with TSS and PM, similar to a Swedish study (Hallberg et al. 2007) where the total metal concentrations correlated strongly with TSS concentrations, with the exception of Cd (Hallberg et al. 2007). The concentration levels depending on the construction phase were not clear, although over the limit values occurred mostly at the finished site (A), and at the excavation/building construction site (C).

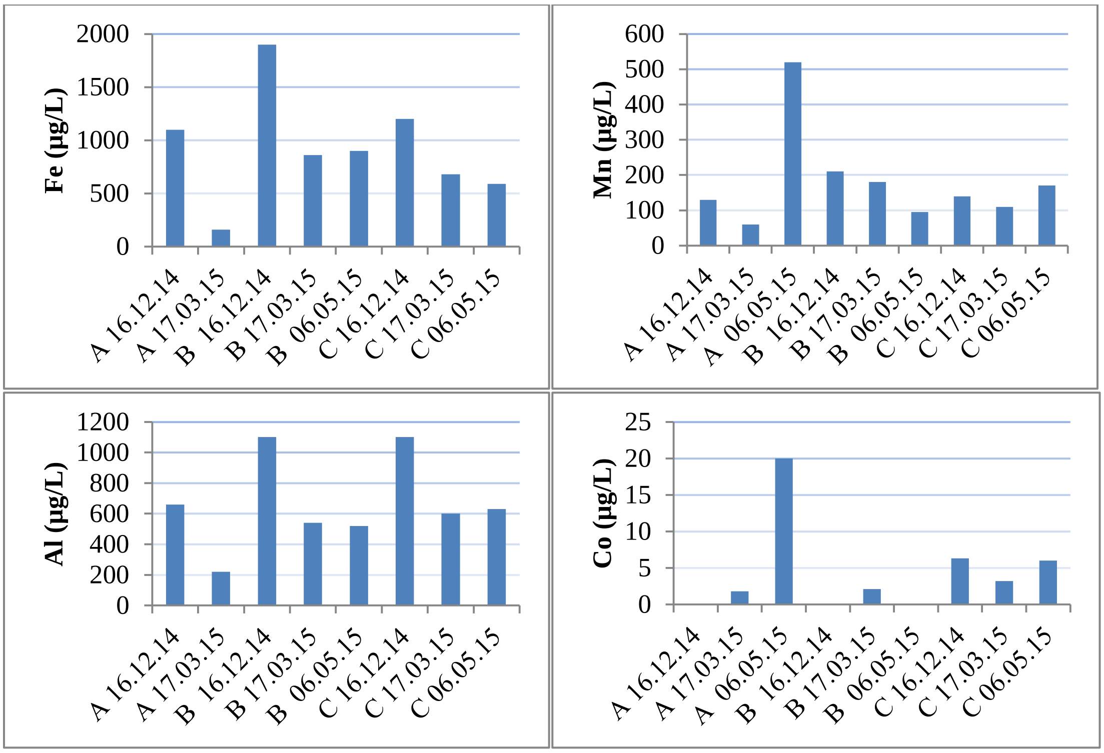

Figure 25. *The concentrations of Fe (with the peak of 36000 µg/L removed), Mn, Al (with the peak of 27000 µg/L removed) and Co in different construction sites and seasons. The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

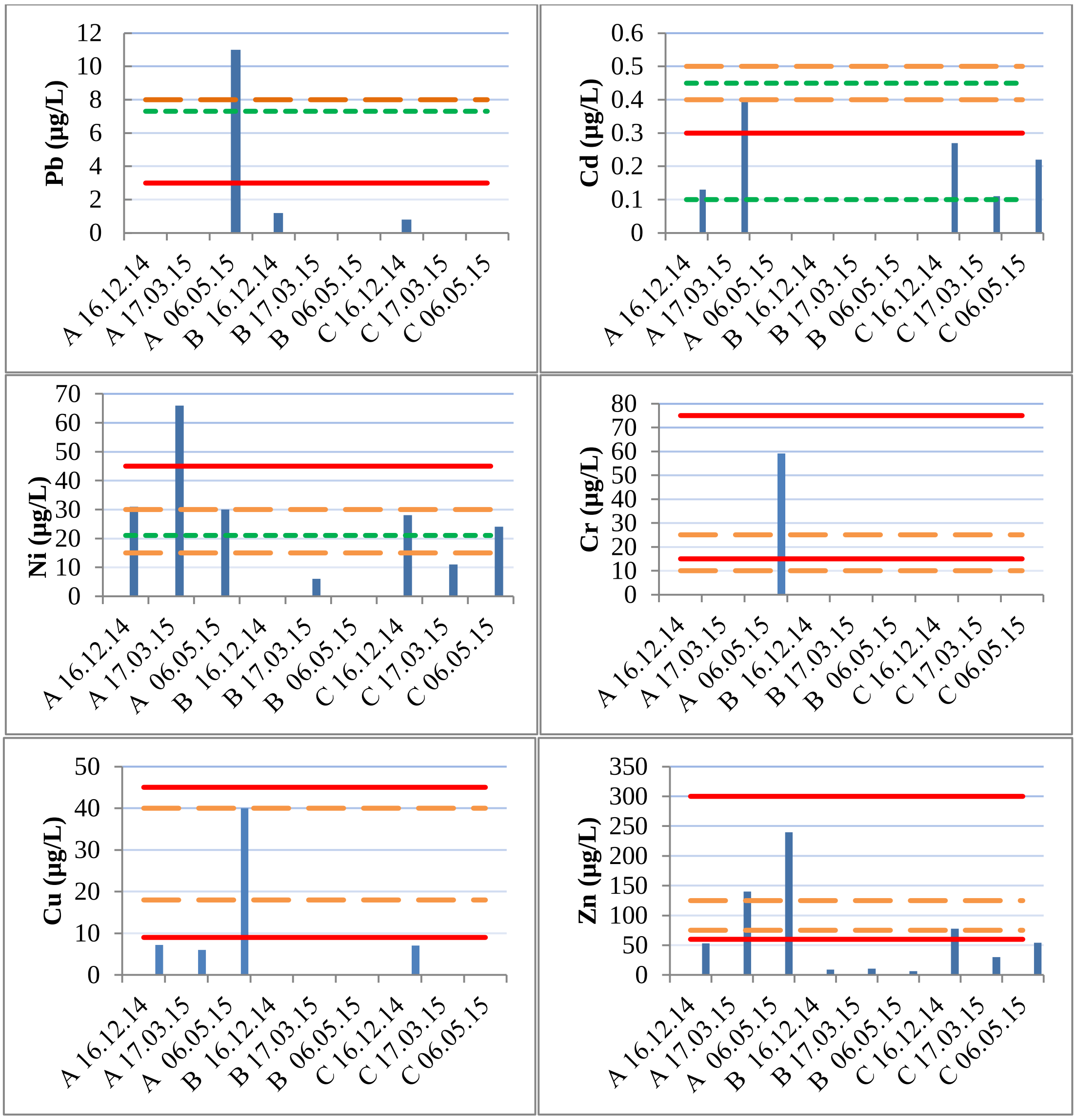

Figure 26. *Pb, Cd, Cr, Cu, Ni and Zn in stormwater runoff in different construction sites and seasons. They are applied with quality limits, which are represented with a continuous line (Stockholm Vatten 2001) with a long dashed line (Riktvärdesgrubben 2009) and with a short dash line (Government Decree 2011). The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

5.1.3 PAH compounds in stormwater runoff

PAH compounds were discovered from stormwater runoff in Vuores (Figure 27); once at the excavation/building construction site (C) after the spring snow melt, and again at the finished site (A) during rain event. Every time they were detected, the PAH compounds were above the guidelines. The particulate association of PAH compounds are recognized (Clark and Pitt 2012), explaining the findings during the rain event on 6.5.2015 and after snowmelt on 17.03.2015.

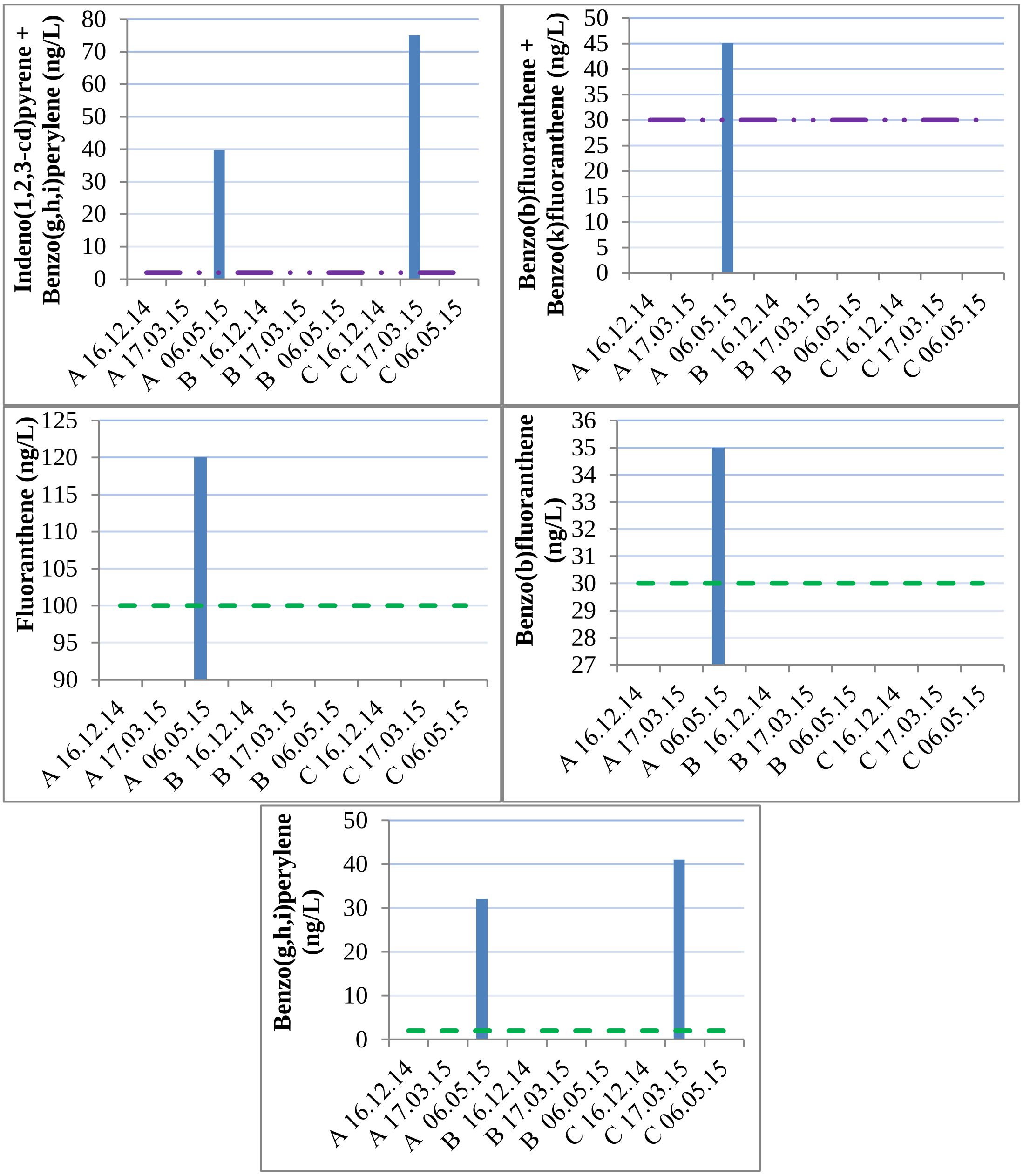

Figure 27. *PAHs in stormwater runoff in different construction sites and seasons. They are applied with quality limits, which are represented with a short dash line (Government Decree 2011) and with a dash dot line (Mannio et al. 2011). The locations were the finished site (A), the excavation related site (B) and the excavation/building construction site (C).*

5.2 Field observations and the inspection of construction site

The construction sites were observed during six field observations trips 18.11.2014–18.05.2015. The object was to observe and discover issues related to construction time stormwater runoff, which would create a frame for inspections. Issues discovered were observed on site or they were deduced to be possible issues and not necessarily originating from Vuores. The findings were also discussed with professionals in construction site inspections and design (Interviews 2015).

5.2.1 Space limitations at construction sites

Spare space was observed to be scarce at construction sites in Vuores. The storing of different construction materials and construction barracks and the actual construction process were observed on sites. At the construction sites, space is acknowledged to be often limited and the properties and lots are small, especially in Vuores. Therefore it would be difficult to place, for example, a sedimentation basin on site. (Interviews 2015.) During field observations, only sedimentation basins, which were in joint use between construction sites, were noted. In Finnish construction ordinances joint runoff treatment is recommended, if stormwater runoff on-site infiltration is not possible. (The Construction Ordinance of Helsinki 2010; The joint Construction Ordinance of Lahti, Nastola and Kärkölä. 2013, p. 21–22; The Construction Ordinance of Tampere 2014; The construction ordinance of Turku 2007.)

The building inspection authority can order the use of a joint runoff management system (The Construction Ordinance of Helsinki 2010; The Construction Ordinance of Lahti, Nastola and Kärkölä 2013, p. 21–22; The Construction Ordinance of Tampere 2014), and the joint system may be required to be implemented on-site before the construction begins (The Construction Ordinance of Lahti, Nastola and Kärkölä 2013, p. 21–22). Joint systems are a potential choice, because source control can often be challenging, although joint systems would require defining the party who is responsible for maintenance (Interviews 2015).

5.2.2 Sediments and erosion

Erosion and sediments are probably the most visible effects of stormwater runoff, and in Vuores the adequacy of ditch erosion protection was poor on several occasions. Most of the observations were located off-site from construction work in a finished site. However, finishing construction should mean finishing the ditches, which would require slope stabilization with, for example, quickly rooting vegetation or more inclusive and widespread erosion protection. There was also an issue with finalizing the surroundings of piping adjacent to construction site ditch (Figure 10). It is probable that the pipe surroundings had received a coating of rougher stone material (Interviews 2015), but without information about the time before the introduction of rougher material, there is no certainty that no finer sediments have departed from this installation.

Preventing erosion and controlling sediments during construction is important also in Finland (FCG 2008, p. 5; FCG 2012, p. 27; FCG 2015, p. 28). Several regional generic stormwater runoff plans imply that stormwater runoff released during construction, especially with disturbed surface soil, have higher concentrations of sediments compared to the finished sites. On the other hand, flow volumes are speculated to be smaller during construction compared to finished sites (FCG 2008, p. 5; FCG 2012, p. 27; FCG 2015, p. 28), but because of erosion and floods, flows also need controls (FCG 2015, p.

28). The autumn rains are seen as a possibility for increased runoff volumes, creating momentary flow complications (Interviews 2015).

The slope stabilization and erosion protection should be a part of finishing a site, but the erosion protection of ditch banks was questioned in this study construction sites and also at finished locations. This is, however, case specific, because in these particular cases (Figure 9) blasted rock at the bottom of a ditch presumably stops the sediment transportation. Thus, the sediment transportation through the stormwater runoff ditches and the sensitivity of the receiving waterbodies should be further evaluated. Perhaps based on erosion potential, certain locations should be covered, for example, with temporary erosion protection until proper vegetation can be established. However, erosion protection requires finances and is often a compromise (Interviews 2015).

Erosion protection should be implemented with exposing only small areas of ground at a time, avoiding rain peaks or snow melts with vast excavations. In extreme cases, weather forecasts could be integrated into construction works. (FCG 2015, p. 30–31.) Soil stabilization methods, such as construction roads, are usually in a good state at construction sites, but slope stabilization, such as mulching and seeding, is not well implemented (Kaufman 2000).

In this study soil piles were discovered without protective fences or similar applications, which is not, as of yet, a standard procedure in Finland (Interviews 2015). However, some of the Finnish ordinances state that the embankings and slopes should be constructed in a way that it would prevent runoff and soil from leaving the site (The Construction Ordinance of Helsinki 2010; The Construction Ordinance of Tampere 2014).

5.2.3 Piping and piping infrastructure

Stormwater runoff drain manholes that were nearly clogged were discovered during field observation trips. They were speculated to be protected from sediments being transported towards the stormwater runoff drainage system (Interviews 2015), which is positive, because clogged drains are undesirable and require maintenance.

In this study, the stormwater runoff drains were also observed to contain sediments outside of construction sites. Maintenance is important in order to protect the drainage network and only treated runoff should flow through it. After constructions, the stormwater runoff drains should be cleaned. (Interviews 2015.) However, constructions often start and finish in different times in the same area, which is the case in Vuores.

5.2.4 Best management practices

BMPs were also targeted at the field observation trips, but they were difficult, if not possible, to discover if constructions were in a later phase, and the visible sedimentation basins were no longer in use. Some plans for construction time runoff BMPs were available, but many of them were not detected. However, a joint sedimentation basin was found and it appeared to be in order, although its outlet protection was not apparent. In addition, a future bioretention area was discovered as a construction time sediment trap. BMPs, which are meant for finished sites, can be used during construction as temporary sediment traps, if the construction time sediments are removed after constructions, before turning the temporary BMP to a permanent BMP (FCG 2008, p. 5; FCG 2015, p. 31). Additionally, the field observations created an idea that construction time BMPs would be designed, but not implemented or their placement would be wrong. This could be due to decisions caused by the terrain or soil conditions at the location.

BMPs recommended for construction sites are sedimentation basins, silt/sedimentation fences (FCG 2008, p. 5; FCG 2015, p. 31; Tampereen Infratuotanto Liikennelaitos 2010, p. 2) and filtration dams (Tampereen Infratuotanto Liikennelaitos 2010, p. 2; FCG 2015, p. 28–30), from which a joint sedimentation basin and filter dams in the ditches were observed in the current study. Filtration could be done with silt fences on land, filtration dams in ditches and if space is lacking, portable clarifier treatment units are suggested (FCG 2015, p. 28–30). Excavating large pools should be avoided, because sedimentation basins at construction sites do not need to detain large flow volumes, only the sediments (FCG 2008, p. 5; FCG 2015, p. 31). A filtration dam should be at the basin outlets (FCG 2015, p. 31). Besides these BMP recommendations, a construction site can be surrounded with soil barriers and if silt fences are used, it is essential that they are installed properly (FCG 2008, p. 5). Natural, already existing terrain should be utilized as much as possible in stormwater runoff management at construction sites (FCG 2015, pp. 30–31; FCG 2012, p. 27) in addition already existing ditches, because natural ditches have lesser erosion potential compared to new ditches (FCG 2015, pp. 30–31). BMPs implemented are not only physical; inspections at the site, meetings with developers and training stakeholders about stormwater runoff improve stormwater runoff management. (City of Bryan 2015.) Whatever is used as construction time BMPs, they are instructed to be present before excavations start. (Toronto Water 2006, p. 24.)

5.2.5 Snow and littering

Snow and littering are presented here in the same context, because littering was observed to increase after snowmelt near the ditches. In the current study, ploughed snow was observed to contain sediments and litter, which were revealed after snowmelt. In addition, pollutants that were not visible could be speculated to be accumulated in ploughed snow, which was not confirmed in this study because neither snow samples nor analyses were done. Finnish ordinances state that snow cannot be stored in public areas and it is recognized that melting waters create problems (The joint Construction Ordinance of Lahti, Nastola and Kärkölä. 2013, p. 22; The Construction Ordinance of Tampere 2014). Although it is common to utilize ditches as snow storage, the placement for ploughed snow should be thought of and limited space at construction sites restrains it. (Interviews 2015.)

Some litter was found near the ditches in Vuores. For example, the Construction Ordinance of Tampere (2014) states that construction time trash should not be found in the surroundings of construction site. Littering is not directly related to stormwater runoff, but more of an esthetic nuisance. Even though littering is considered a bigger problem than contaminants leaching from the construction materials, the ditches should not be filled or used as storage and trash and littering should be cleaned up after finishing constructions, at the latest. (Interviews 2015.)

5.2.6 Maintenance and completing the construction site

In this study, it was unclear which locations should be classified as finished ditches and which are parts that are supposed to treat the construction time stormwater runoffs. Whichever is the case, sediments were observed especially after snowmelt in the ditch system in Vuores. The sediments were probably partly detented along the ditches, but some of the sediments could be released to the south side of Ruskontie and further on to Koipijärvi. The maintenance of ditches is important and sediments should be caught early on in the system, which is complicated by gradually progressing development and constructions.

A part of the finished system was observed to contain and to be able to transport sediments (Figure 18). However, the fact that sediments are detained in this particular place is good, but removing them requires maintenance (Interviews 2015). Detrimental stormwater runoff should not be discharged from construction sites (The Construction Ordinance of Helsinki 2010) and therefore stormwater runoff should be treated before they enter to the finished stormwater runoff management system to prevent clogging (FCG 2012, p. 27). For example, filtration dams are seen beneficial before construction time runoff is discharged to finished systems (Interviews 2015).

5.3 Ensuring proper stormwater runoff management during construction works

5.3.1 Planning the management of construction time stormwater runoff

The management of construction time stormwater runoff should be included in all levels of planning. (FCG 2012, p. 34.) The plans for the management of construction time stormwater runoff have only recently become a requirement for the construction permits in Tampere (Interviews 2015). Stormwater runoff management plans related to construction works are also demanded in other parts in the world, but in more detail (for example City of Bryan 2015; Toronto Water 2006, p. 24). For example, stormwater runoff pollution prevention plan (SWPPP) is required for sites which are one acre or larger in order to disturb soil surface. SWPPP contains, for example, the identification of possible pollution sources, pollution reduction methods, timing of the excavations and the locations of excavations and BMPs on a map. The plans should also cover the permanent and temporary stabilization methods and their timetable. (Darlington County 2015.) The plans for stormwater runoff may furthermore include the defining of the time that soils are allowed to be bare and the maintenance requirements for sediment controls and other BMPs. (USEPA 2015a.)

Planning construction time stormwater runoff management should be more thorough if receiving waterbodies are sensitive. For example, stormwater runoff could be directed to a different direction if it protects sensitive waterbodies, which has been the suggestion in one part of Vuores, Isokuusi, where stormwater runoff should be directed south instead of north where a clean and protected Särkijärvi is located. (FCG 2012, p. 27.) Also effective erosion protection, with erosion textiles and mats, is in order in extremely sensitive cases. (FCG 2015, pp. 30–31.) Furthermore, the requirements for stormwater runoff treatment at construction site discharging into sensitive waterbodies should be stricter, and construction time inspections should be more frequent, including inspections during rain events.

5.3.2 Inspecting construction sites to improve stormwater runoff management

Stormwater runoff management inspections at construction site should be formulated to be clear and inclusive. The inspections are just starting to gain a better understanding in Finland. Inspections are essential for the construction time stormwater runoff management to function well and to reveal weaknesses (USEPA 2015b). The deficiencies, which are most often found at construction sites, are missing temporary or permanent soil coverage, missing on-site sediment controls, temporary stockpile controls, the lack of drain inlet protection, missing construction entrance BMPs, faulty solid or hazardous waste management, improper on-site dewatering and inadequate BMP maintenance (USEPA 2015b). Several of these were observed in Vuores. Furthermore, the inspections should also consider the case specific nature of construction time runoff management, because their controls must be designed case-specifically depending on the construction sites (FCG 2015, p. 28; FCG 2012, p. 27). Penalizing the violations is important in order to improve construction time stormwater runoff management and the ordinances are useful in enforcing and penalizing the violations in the other countries (USEPA 2015a). Also in Finland, a clear penalty system is seen as a good guidance method for construction time runoff management (Interviews 2015).

In Tampere, the general construction inspections are made at local construction sites, but they are often limited inside the site borders and the surroundings are not usually observed (Interviews 2015). For better management of stormwater runoff, the inspections should include observing the discharge location outside the construction site limits, at least visually, to ensure the sufficient treatment level.

The construction time stormwater runoff inspections should be done once a week or once a fortnight and within 24 hours after a certain rain event (Darlington County 2015). Inspections during and/or after rain events are important also based on the results obtained in this study. The inspections would require additional resources, and involving, for example, developers or other stakeholders for inspections is possible. Actually, in another part of world, the city has a possibility to delegate the post-construction site inspections and monitoring to the developer (Toronto Water 2006, p. 28), which could also be explored in Finland.

To facilitate the inspections, a profound inspection form for stormwater runoff management during construction is essential (City of Bryan 2015). A construction stormwater runoff inspection form could utilize technology and be, for example, an application for a tablet or a smart phone (Inspect2GO 2015), which could also have a feature for photographing locations and linking them to the inspection form.

A protocol was created in order to facilitate inspections of construction time stormwater runoff management, identifying different possible construction phases, including planning and post-construction phases and some of the potential inspection targets (Figure 28 and Appendix 2). The planning of the construction time stormwater runoff management and its viewing by authority early on is emphasized. A wide variety of BMPs can be utilized in construction sites, and they and their maintenance should be subjected to inspections in multiple construction phases. Site finalization and post-construction surveillance are also important and ensure the proper deployment of stormwater runoff management system after construction. The pollutants discovered in this study indicated that many pollutants can be found in construction time stormwater runoff, especially during the rain event and with association to PM, which is why the functionality of BMPs should be inspected also during rain events.

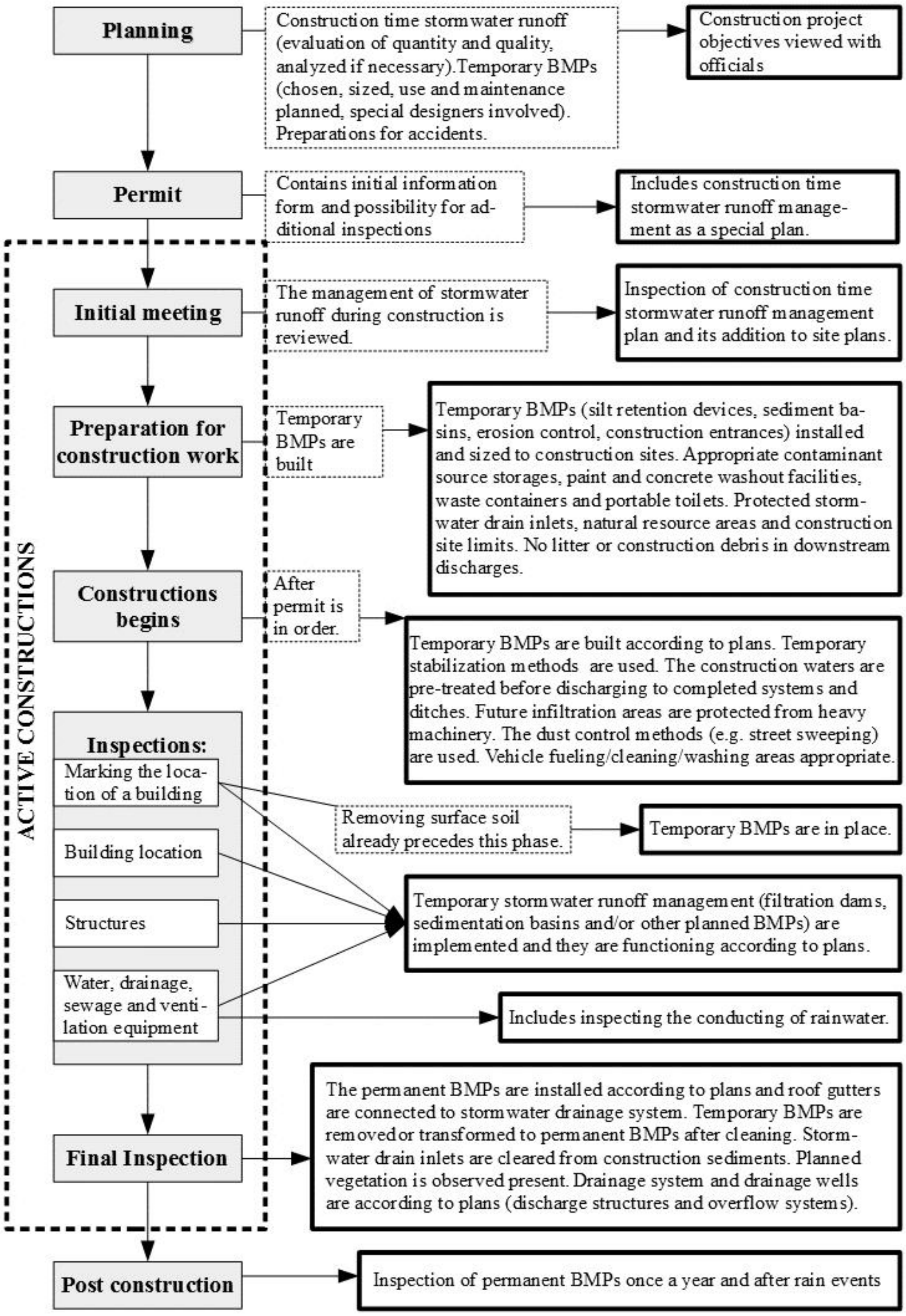

Figure 28. *Possible stormwater runoff management inspections (bold outlined boxes) targeted to different phases (grey boxes) of a construction process beginning from planning and ending after constructions are completed with some additional information (dash lined boxes). The information is compiled based on this study, Ilmastonkestävä kaupunki (2015a), Ilmastonkestävä kaupunki (2015b), Section C (2013), The City of Bryan (2015), The City of Tampere (2015b), The City of Tampere (2015c) The City of Tampere (2015d), The City of Tampere (2015e) and The City of Vantaa (2015).*

6. CONCLUSIONS

If not managed properly or at all, construction time stormwater runoff causes erosion, flushed sediments and degradation in the receiving waters. In some countries, stormwater runoff management has been taken into consideration well, while for example in Finland it is just beginning to receive attention.

The main objective in this thesis was formulating the recommendations for construction time inspections based on observations in construction areas. Another objective was to evaluate what pollutants are found in the construction site stormwater runoff.

Several pollutants were found in the stormwater runoff. The rain event raised TSS concentrations, turbidity and many of pollutants that are associated to PM. The relation to rain events could have been established better with more rain event time sampling. It was obvious that as rain events levelled up the pollutant concentrations, some of them like TSS, heavy metals and PAHs were over the quality limits of stormwater runoff. Nitrogen surpassed the guidelines irrespective of flow and rain event. Different pollutants responding differently for the rain event indicate the need of the BMPs to function properly during rain events and dry periods. The samples, however, were not completely obtained from construction site runoff, because access to purely this type of samples was impossible due to the gradual development of the area and limitations in staying outside of construction fences.

Field observations located many inspection needs relating construction time stormwater runoff management. Particularly sediments and erosion protection should be developed. Winter and snow also require attention regarding stormwater runoff management. Snow needs space to be ploughed in, because ploughed snow contains contaminants and sediments, which need to be secured. As snow melts it easily transports sediments in the ditch systems and flushes out pollutants. In addition, site finishing is important and several visited locations looked unfinished although they were completed. Field observations would probably have revealed more insight into the matter if inside the construction site fences were accessed. Also observing different locations besides Vuores would have resulted in more profound understanding of the local aspects of this subject.

The present findings indicate that construction areas would benefit from thorough inspections related to stormwater runoff management. Proper enforcement actions together with thorough inspections would affect construction time stormwater runoff management positively. The plans of stormwater runoff management during construction should be required before the actual construction begins, and they need to be adjusted to according to the sensitivity of receiving waterbodies. Instructions should be intertwined in different construction phases and in different seasons. Including different stakeholders in the inspections would alleviate both the stress for the main inspector and personnel shortage. In this case, the stakeholders should be educated regarding construction time stormwater runoff and why it needs management.

In Finland, the construction time stormwater runoff management has not been the objective of many studies. Various stormwater runoff pollutants and their response to seasons need further research. In addition, the effects of seasonality on BMP performance should be studied. The regulations for construction time stormwater runoff are forming gradually, and only recently Tampere has adopted the requirement of a construction time stormwater runoff management plan as part of applying for construction permit. Efficient inspections are important to follow through a properly managed stormwater runoff during construction, which is why this thesis offers a frame for inspections. Based on previous research and this study, more information is needed about stormwater runoff and its management during construction.

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APPENDIX 1: WATER QUALITY GUIDELINES

Water quality limits for selected parameters for stormwater runoff (Stockholm Vatten 2001), lakes and sea (Riktvärdesgrubben 2009), harmful substances for aquatic environment and hazardous industrial (Government Degree 2011) and household chemicals in the aquatic environment (Mannio et al. 2011).

Parameter		Stockholm Vatten 2001		Riktvärdesgruppen 2009		Government Decree 2011			Mannio et al. 2011, pp. 36, 37
		lower limits	higher limits	lower limits	higher limits	AA-EQS	MAC-EQS lower limits	MAC-EQS higher limits	
SS	mg/L	50	175	40	75				
TP	mg/L	0.1	0.2	0.16	0.25				
TN	mg/L	1.25	5	2	3				
Pb	µg/L	3	15	8	15	7.3	is not applied		
Cd	µg/L	0.3	1.5	0.4	0.5	0.1	0.45	1.5	
Cr	µg/L	15	75	10	25				
Cu	µg/L	9	45	18	40				
Ni	µg/L	45	225	15	30	21	is not applied		
Zn	µg/L	60	300	75	125				
Mineral oils	mg/L	0.5	1	0.4	0.7				
PAH	µg/L	1	2						
Benzo(g,h,i)perylene	ng/L					2	is not applied		
Fluoranthene	ng/L					100	1000		
Benzo(b)fluoranthene	ng/L					30	is not applied		
Indeno(1,2,3-cd)pyrene + Benzo(g,h,i)perylene	ng/L								2
Benzo(b)fluoranthene + Benzo(k)fluoranthene	ng/L								30

APPENDIX 2: PROPOSED INFORMATION FOR THE INPECTIONS

Phase	**Additional information**	**What should be in order for the construction project to proceed?**
Planning phase	The proper temporary construction time BMPs and related equipment are chosen, planned, [1] sized and also their use maintenance is planned. [3] The quantity and quality of stormwater runoff is evaluated from before, during and after construction. Also sampling and analyses are organized if needed. [2, 3] Preparations for surprising events [2] and accidents. [3] Special designers and planners should already be involved in this phase. [5]	Is the objective of projects stormwater runoff control gone through with the officials
Permit phase	A form for initial information about stormwater runoff control. [4] The terms of construction permit could include special inspections and reviews for stormwater runoff. [8]	The required permit appendices are present. [5] One of the permit special plans could be the construction time stormwater runoff management plan. [6]
Initial meeting	The management of stormwater runoff during construction is reviewed.	Stormwater runoff management planned and is its construction time management added to site plans. [3]
Preparation for construction works	he construction time BMPs are built and inspected if possible in initial inspection [1] The pre-construction can begin if terms are agreed at the initial meeting before permit is probated. The pre-construction contains tree felling, excavations, blasting and pile-driving. In this case also the proper plans for construction time stormwater runoff management needs to be verified. [7]	The stormwater runoff management intended for construction time and sized appropriately? [2] The construction time BMPs are situated off the pathways. [2] The temporary BMPs are installed (silt retention devices, sediment basins, slope protection methods, temporary construction entrances and exits [9] The storm drain inlets, natural resource areas and construction site limits are properly protected. [9] The possible contaminant sources

			are recognized and stored properly. [9] There is no litter, trash construction debris or materials observed downstream of discharges. [9] Paint and concrete washout facilities marked and maintained. [9] The waste containers are present and the portable toilets are properly installed. [9]
The actual construction begins		Constructions can begin if the permits and required special plans are in order.	The construction time BMPs built according to plans and out of the pathways. [3] The temporary stabilization methods are used (For example a grass mats or geotextiles). [9] The construction waters are properly pre-treated before discharged to finished stormwater runoff management systems and ditches. [3] The locations that are planned to be finished site infiltration areas are protected from heavy machinery etc. [3] If construction time BMP is used as permanent BMP for finished site, it should be protected from erosion if needed. [2] The dust control methods in use (for example street sweeping). [9] Vehicle fueling/cleaning/washing areas are in order. [9]
Inspections	Marking the location of a building [5]	In here the construction time BMPs should already be present at the latest. Removing surface soil already precedes this phase [5]	The construction time stormwater runoff management is implemented according to the plans. For example the filtration dams, sedimentation basins and/or other planned BMPs are implemented and they are functioning according to plans.
	Inspection of building location [5]		
	Inspection of structure [5]		

	Inspection of water, drainage, sewage and ventilation equipment [5]	includes inspecting the conducting of rainwater [5]	
Final site inspection			The permanent BMPs installed according to plans. [1] The roof gutters are connected to stormwater drainage system? [9] The temporary BMPs are removed. [9] The temporary BMPs transformed to permanent ones (for example infiltrating and filtrating BMPs) have been treated appropriately (if the BMPs were used during construction, the construction time sediments and sludge are removed). [2, 3] The stormwater inlets are cleared from construction sediments and debris? [9] The planned vegetation is present. [9] The drainage system and drainage wells are in order and according to plans (the discharge structures and overflow systems)?
Post-construction phase			The inspection of permanent BMPs once a year. [1] The inspection of permanent BMPs after a predetermined rain event. [1]

[1] Section C 2013
[2] Ilmastonkestävä kaupunki 2015a
[3] Ilmastonkestävä kaupunki 2015b
[4] The City of Vantaa 2015
[5] The City of Tampere 2015b
[6] The City of Tampere 2015c
[7] The City of Tampere 2015d
[8] The City of Tampere 2015e
[9] The City of Bryan 2015